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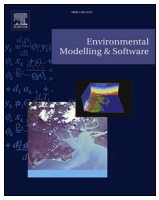

Wikis as collaborative knowledge management tools in socio-environmental modelling studies

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ABSTRACT

The data requirements of many socio-environmental system (SES) modelling studies have increased substantially in recent years. This has made the already challenging task of data compilation, retrieval, and sharing progressively more difficult. Recognising the current lack of best practice for knowledge management in SES modelling studies, we propose using SES wikis as a means of addressing these challenges. Wikis have attributes that make them well suited to complex knowledge management tasks and their hierarchical, interconnected, algorithmic logic closely fits with the logic needed in SES model design. In this article, we describe how wikis can be used at each stage of the SES modelling cycle, and we discuss our experiences of putting the approach into practice. We conclude that while SES wikis can be time consuming to initially develop, they have the potential to significantly improve the quality, transparency, and efficiency of SES modelling projects.

1. Introduction

As the sophistication, ambition, and empirical verisimilitude of socio-environmental system (SES) modelling studies has increased, their data requirements have grown ever more onerous (Janssen and Ostrom, 2006; Laatabi et al., 2018; Polhill et al., 2016). SES models typically encompass a wide variety of processes and entities, necessitating the collection and integration of cross-disciplinary information (Janssen and Ostrom, 2006; Linstädter et al., 2016; Ostrom, 2007; Smajgl et al., 2011; Steger et al., 2021). Where modelling is bottom-up, as is the case with agent-based modelling (ABM) (Polhill et al., 2019), this information will usually need to be heavily disaggregated. Detailed knowledge of temporal dynamics and spatial heterogeneity may also be needed (Smajgl et al., 2011). Researchers who pursue a grounded theory or generative modelling approach – where the aim is to derive possible explanatory causal mechanisms endogenously rather than impose them (Epstein, 2006) – may additionally need to contend with high uncertainty around what information they will ultimately require, forcing them to engage in broad reaching, speculative data collection, until the form of their final model becomes clear.

At present, no widely accepted best practice has been established for knowledge management in SES modelling studies. Though science-wide initiatives like *The Turing Way* have sought to nudge researchers towards better research data management, most modellers currently appear to employ ad hoc, informal means to manage their data and domain knowledge. For example, in an ABM study, findings from individual data gathering exercises (e.g., interviews, focus groups, household surveys) might be analysed and stored separately, with synthesis occurring only as the model is developed. It is also likely that many modellers draw on tacit knowledge gleaned during fieldwork that is not written down or otherwise recorded, in part because there are few tools suited to documenting disparate SES knowledge.

These practices are problematic. Most critically, they can make ongoing assessment of data adequacy difficult during the data gathering phase; they can make retrieving relevant knowledge unnecessarily challenging during the modelling phase; they can make projects

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dependent on researcher recall; and fragmentation may increase the chance of there being contradictory data, meaning that researchers lack a "single source of truth" from which to work (Markus, 2001). Given that researchers often move between projects, and other researchers may wish to draw on existing data for their own work, storing data in a way that makes it understandable independently of the original researcher can be hugely important as White et al. (2013) have previously noted. A dearth of knowledge sharing is also an issue in the SES modelling community – which is at least partly attributable to the lack of suitable formats for packaging and distributing mixed-methods SES knowledge. Consequently, we feel that both researchers and the communities in which they operate would benefit from improved knowledge management practices.

While many proposals have been made for improving aspects of the documentation process in social and ecological modelling studies, they all have their limitations when it comes to addressing these knowledge management challenges. The ODD protocol (Grimm et al., 2006, 2010, 2020) and the ODD + D protocol (Müller et al., 2013) encourage researchers to discuss their model's empirical background and to provide an overview of their input data. This is valuable, but in practice the background that is set out is often highly summarised so only a fraction of the case study knowledge is conveyed. Moreover, the protocols only come into play during the modelling phase of projects, leaving the challenges of the earlier phases unaddressed. The more recently proposed ODD+2D protocol of Laatabi et al. (2018) asks researchers to provide additional details of how data has been selected, processed, and mapped to model agents and their environment, addressing some of the gaps in the earlier ODD protocols. However, it is still not intended for use in the pre-modelling phase of projects and the focus remains on communicating the information that directly informed a model's design, rather than on aiding researchers in the core knowledge acquisition and management process. The TRACE framework of Schmolke et al. (2010) goes further than most modelling study documentation proposals in that it calls on users to document the whole research cycle and is more explicit in asking researchers to explain the rationale for modelling decisions. Yet, while this encourages greater discussion of empirical context and data matters, it is still not the same as a knowledge management system. It was also not purposefully designed for projects that involve a significant amount of primary data collection, so it is not especially attuned to the needs of such projects.

This paper aims to help the SES modelling community address knowledge management challenges by describing a systematic approach for gathering, cataloguing, and sharing knowledge for use in SES research, described here as the 'wiki method'. It has the potential to significantly improve the quality, transparency, and efficiency of SES modelling projects, particularly those which involve integrating and managing large volumes of quantitative and qualitative data. In *Section 2*, we explain the SES wiki concept, discuss the attributes of wikis, and explain why they are a good match for the needs of SES modellers. In *Section 3*, we share our experience of using the wiki method in the development of an ABM of a Nepalese mountain community (Roxburgh, 2019; Roxburgh et al., 2021). In *Section 4*, we offer guidance as to how it can be employed at various stages of the research process. And in *Section 5*, we critically reflect on its strengths and limitations, and discuss how it can be employed most effectively by SES modellers.

2. Wikis and their relevance to SES research

A wiki is a publication format that facilitates collaborative documentation and knowledge management (Roxburgh et al., 2021). A typical wiki consists of a set of webpages that can be edited by a user community through a web-based interface (Baumeister et al., 2007). Each page addresses a particular topic (Lange, 2007; Sauer et al., 2005; Wagner, 2004). Pages can be added and edited overtime as users deem fit. They can also cross-reference one another using hypertext, a feature that promotes "meaningful topic associations" and reveals "dependencies among concepts" (Lange, 2007, p. 120).

Wikis have attributes that make them well suited to complex knowledge management tasks. They are highly dynamic, allowing content to be continually added and refined as understanding evolves (Baumeister et al., 2007; Lange, 2007; Mietchen et al., 2011; Piccoli et al., 2000). They are also suited to co-creation as little training is required to partake in their development and software typically allows for distributed editing. This means they can enable broad-based participation and the harnessing of collective wisdom if managed with care (Dai et al., 2013; Majchrzak et al., 2013; Sauer et al., 2005). Furthermore, the hierarchical, interconnected nature of wikis closely fits with the logic needed in SES model design. It reduces complex systems to neat, digestible elements while not divorcing these elements from context. The way topics are discussed in a modular fashion is in keeping with how models tend to be structured, while the links make it easier to see and follow the threads that link topics together. Through centralising knowledge, wikis additionally make it easier to locate information when it is required and to identify gaps in knowledge that need to be filled. By encouraging knowledge to be made explicit, they also help in making it researcher independent, facilitating collaborative work and knowledge reuse. On top of this, as wiki software typically records edit histories, they are suited for use in academic contexts as such tracking facilitates transparent review (Mietchen et al., 2011, p. 55).

The attributes of wikis, and their alignment with the knowledge management needs of SES modelling projects – particularly those that involve primary data collection – are summarised in Table 1.

3. Our experience: the Nepal wiki

We originally developed the SES wiki approach in 2015 to aid information collection about a smallholder community in Nepal in which we were conducting fieldwork. Our intention was to create a detailed ABM of the village to examine the effects of various future stressor scenarios. While we had identified climate change as our chief stressor of interest, the aim of fieldwork was to identify intersecting stressors and key social and environmental processes on the ground without prejudice. As such, the field investigations necessary were, by their nature, uncertain. As it was unclear whether we would be able to return to the field site after the initial data collection phase, we decided to take an all-encompassing approach to data collection, gathering information on a wide variety of potentially pertinent topics to hedge against the uncertainty. The SES wiki approach was conceived as a means to manage this multifarious yet interlinked information and to keep tabs on gaps in our knowledge that still needed to be addressed. We also recognised the potential for collaborative development that wikis offer meant we could empower villagers to participate directly in the knowledge curation process.

We began development of our wiki by mapping out a comprehensive set of topics that required exploration to gain a holistic understanding of the study site. Topics were identified by examining past ethnographic literature on rural Nepal (Adhikari, 2000; Fricke, 1993; Miller, 1990; Whelpton, 2005) and by drawing on our prior experiences in the region, including a scoping trip to the field site. This allowed us to prepare a tentative framework for the wiki before commencing the main phase of data gathering. It was fully expected that some topics would fade in importance while others would strengthen or be introduced as investigations deepened.

Two villagers from our field site were recruited to populate the wiki: one male and one female, both 26 years old. A gender balanced team was chosen due to the potential for knowledge and perceptual differences between men and women in the village (Momsen, 2006). As the task required a week of work on the part of the recruits, and therefore a significant opportunity cost in respect to paid labouring, those who assisted us were provided with financial remuneration.

The two recruited villagers shared their knowledge of the wiki topics with our Nepalese research assistant, who transcribed their responses

Table 1
Features of wikis and their relevance to SES research.

Wiki feature	Relevance to SES research
Centralised information repository: Information is stored in a modular system while maintaining linkages to other elements and to higher-level contexts.	• Easy to locate and retrieve information. • Helpful for identifying knowledge gaps. • Makes knowledge researcher-independent. • Modular fashion is similar to how SES models are structured. • Clearly defined links make it easier to identify and understand interconnections between topics. • Wiki articles can be referenced in other model documentation (e.g., ODD) and project outputs.
Dynamism and flexibility: Various forms of information can be continuously updated, contextualised, and refined as knowledge evolves. Flexibility of form can accommodate a wider range of culture-level qualitative and structural data than standard forms of data sharing.	• Highly suited to iterative knowledge acquisition. • Highly suited to handling non-linear, evolving, complex and networked information. • Can incorporate semantic enhancements, like weblinks and metadata. • Can incorporate different types of media (e.g., pictures, maps, data tables) as well as text.
Ease of use: Wikis are designed to be quick and easy to navigate and edit.	• Little training is required for users and contributors. • A web browser is sufficient to access basic packages. • Ease of use facilitates equality of opportunity to participate and can partially mitigate power issues linked to dominant knowledge (see *Section 5.2*).
Facilitation of knowledge co-creation and convergence: Multiple users can contribute and edit, and contradictory or disputed information can be flagged and reviewed.	• Enables harnessing of collective wisdom and broad-based participation. • Easy to spot and resolve contradictions while still in the field. • Verifiability standards can be incorporated to reduce the likelihood of problematic content arising (e.g., it might be decided that only statements that can realistically be verified by another party can be included (Wikipedia, 2020a)).
Transparency: Edit histories can be tracked and earlier versions can be reviewed.	• Gives insight into the evolution of ideas. • Gives stable reference points despite dynamic nature.

initially in Nepalese before subsequently translating them to English. Each evening, the research team reviewed the articles, identifying issues that merited further probing the next day. Much of the work was done in a quiet café near the village to minimise the chance of interruption. However, data collection also took place in the village as the recruits consulted with other villagers to gather information about topics that they were less sure about. Sometimes this was done with the research assistant present, and sometimes they worked by themselves, bringing their notes to the research assistant later in the day to be translated and typed up. An example of one of the wiki topic pages is given Fig. 1.

As the recruited villagers populated the wiki articles, they were encouraged to suggest other topics to add – something to which they responded positively. This later proved valuable: the 26-year-old male recruit, for example, proactively added details of the construction process to the housing topic. As the April 25, 2015 earthquake razed the houses within days of the initial fieldwork phase concluding, necessitating a complete reconstruction, this became extremely pertinent as it providing us with the parameters necessary to begin modelling the recovery process. The recruits were also asked to review the transcribed articles as the wiki developed to ensure they accurately reflected their inputs.

The research team initially saw our role as simply to ensure as-broad-as-possible coverage of topics and to ask probing questions where articles seemed underdeveloped or lacked clarity. Only occasionally did we decide to remove content. For example, we deemed anecdotes about individual relationships to fall outside the wikis remit. Although plenty of the details in the wiki ultimately proved superfluous to our needs, they aided in building a holistic picture of the case study site and in creating a document that we recognised as being of potential value beyond the immediate aims of our study.

We only began adding content to the wiki ourselves after the participants had completed the bulk of it. Most of what we added was based on insights gleaned through focus groups, household surveys, and process tracing exercises that we conducted alongside wiki development, but later we also added some information derived from the literature which helped deepen understanding and set the village's particularities in the wider context. We sought to be sparing in the edits made so as to retain the voice of the participants in the articles, though there were some topics which needed substantial amounts of supplementary core content, such as quantifying fertility and mortality. Understanding and modelling such processes well necessitates data gathered at much larger scales than our village offered and over a far longer time period than our fieldwork allowed. We therefore drew heavily on third-party sources to inform these elements of the wiki, with participant contributions taking more of a secondary role. The final topic structure used in the Nepal field site wiki is shown in Fig. 2.

When we came to do the modelling itself, finding the information of interest was made straightforward by what essentially constituted a master document. We were able to refer to the relevant pages in the wiki while working on a sub-section of the model rather than constantly needing to search through separate notes, data files, and transcripts. For example, when parameterising costs, we could simply refer to the expenditure section of the wiki and where further details were needed (e.g., the date when marriage expenses are likely to be incurred within a given year), we could follow links to the relevant topic directly from the expenditures page. We rarely encountered knowledge gaps due to the wiki's comprehensive nature and were able to let the importance of variables and processes 'emerge' from the bank of knowledge we had gathered in something akin to a grounded theory approach. Potential connections between topics were made apparent by the interconnected nature of the wiki (e.g., how household structure influenced migration decisions), which assisted us in thinking through the model logic. Furthermore, as much of the information was written from the perspective of research subjects, it provided valuable insights into decision-making processes that we could draw on for the model. For example, it detailed how youngsters go about deciding whether to continue in education and which livelihoods they might pursue.

Confidentiality issues prevented us from openly publishing the wiki, but we were able to summarise many of the wiki articles for inclusion in our project outputs (e.g., Roxburgh, 2019). After having built a detailed model of our mountain community for our original study and fulfilling our original aims (Roxburgh et al., 2021), we realised there was information in the wiki that would allow us to reconfigure the model so we could explore new research questions without needing to return to the study site. This led to us undertaking a study on seasonality in food security – a topic we had not explicitly set out to study during the original fieldwork. The wiki provided us with crucial parameters for this, as well as valuable information about household food consumption behaviour and how they manage food and financial stress – behaviours we could recreate in a stylised way in the model.

4. Guide to using the wiki method

The SES wiki approach that we envisage interfaces with various stages of the research and modelling process. This section offers

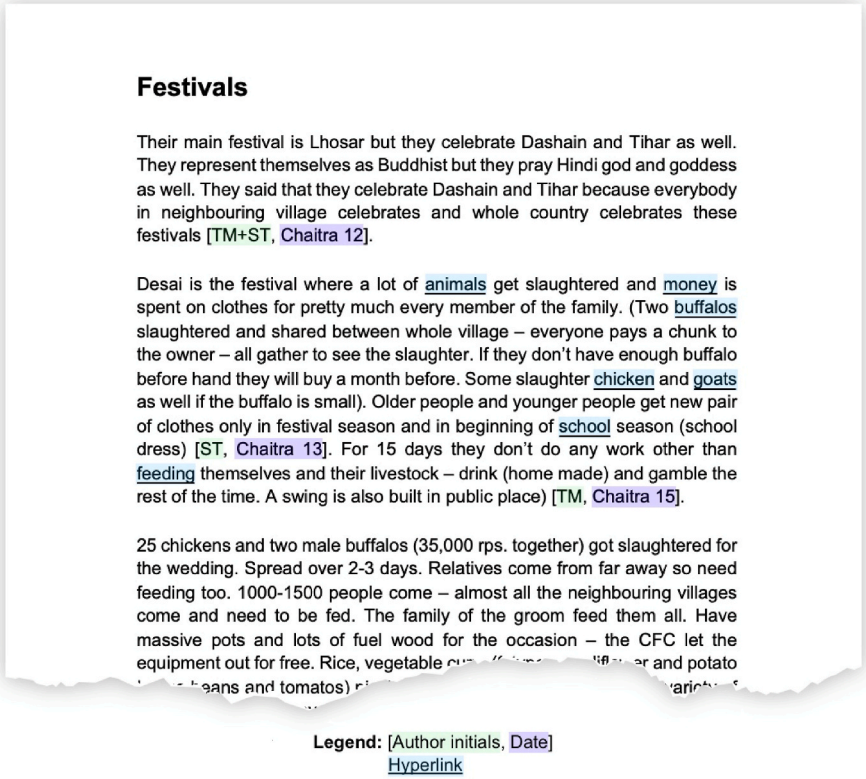

Fig. 1. An example of one of the wiki topic pages. Two individuals contributed, with their insights typed up and then translated by our Nepalese research assistant. Note that the dates used are based on the Nepali calendar (Source: Authors).

guidance as to how it could be most effectively employed to add value at each stage. Fig. 3 shows how the wiki approach can fit within the iterative modelling cycle (as described by Railsback and Grimm, 2012) and the modelling notebook and TRACE documentation approaches (Schmolke et al., 2010).

Fig. 4 shows the recommended stages and processes of the wiki approach, which are discussed in more detail in the following sections. The recommendations assume the use of the wiki approach in a project where primary fieldwork is being conducted as this is one of the situations where the wiki approach can provide the most value, therefore, some recommendations may not be applicable where this is not the case. We aim not to be overly prescriptive as the needs, preferences, and constraints of research projects are varied (Müller et al., 2014). We welcome creative uses of the SES wiki concept, meaning that researchers should not feel bound to this workflow or the subsequent guidance.

4.1. Preparing the wiki

4.1.1. Determine purpose and preliminary structure

When using the SES wiki approach, it is firstly important to reflect on the purpose of the wiki to ensure that it is constructed and used effectively. Project research questions, hypotheses, geographical scope, scales of interest, and intended outputs will all have a bearing on subsequent decisions about how to structure and populate the wiki, so it is sensible to consider these matters early. For example, if there is a desire to make fieldwork data available to other researchers, particular effort should be made to make the wiki presentable and to ensure there is sufficient clarity and detail for it to be of use beyond the initial study. This needs forethought as it will be difficult to do retrospectively.

If researchers wish to embrace a grounded theory style approach to development of the wiki, they need not pre-define topic pages at the outset of data collection. However, drafting a provisional 'skeleton' structure can aid data collection planning and streamline the documentation process. The project research questions, empirical context, and modelling approach, along with Ostrom's (2007) SES analysis framework, can provide inspiration for this structure. We recommend setting a low threshold for determining which topics merit inclusion as their importance can be difficult to determine in advance. For example, we assumed that cultural events and animal lactation cycles would only be of minor relevance when we began our fieldwork, yet they ultimately proved to be highly significant. Being relatively comprehensive in the breadth of the wiki topics not only reduces the likelihood of information being missed and additional fieldwork being required, but also provides valuable broader context to the case study site and increases the chance that the wiki is of practical use for other research studies. It also allows scope for changing study direction or extending models later to address additional questions. Topics can be graded by perceived criticality and worked through in order of priority to capture maximum useful information within the time allowed.

4.1.2. Select software

Before commencing fieldwork, it is important to select software in which to create the wiki. There are two main options: (a) purpose-made wiki software or (b) creating a quasi-wiki with word processor software. Purpose-built wiki software offers valuable data management features such as automated authorship tracking and version control. These features allow the evolution of wikis to be recorded transparently and protect against accidental deletion of knowledge when editing (Majchrzak et al., 2013). Many also offer syncing to a cloud which provides a simple and reliable back-up of field notes and can allow multiple contributors to work simultaneously, which makes collaborative development easier. Most wiki software is compatible with smartphones so equipment availability should rarely be a problem. Rather than recommending a specific wiki software, we would point the reader to the excellent list of options on (unsurprisingly) Wikipedia (2020b), many of which are free and extensible. Downsides of wiki software are

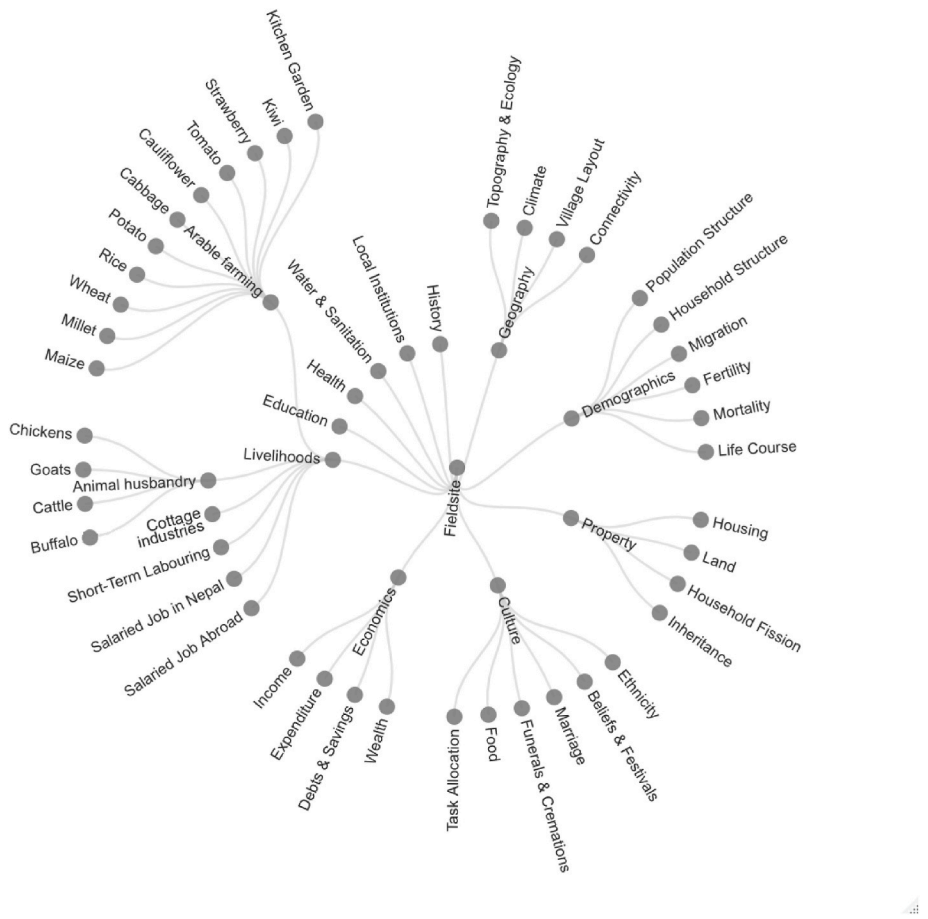

Fig. 2. Diagram showing the final Nepal wiki structure. Each node is a topic page in the field site wiki and contains hyperlinks to the other topic pages (Source: Authors).

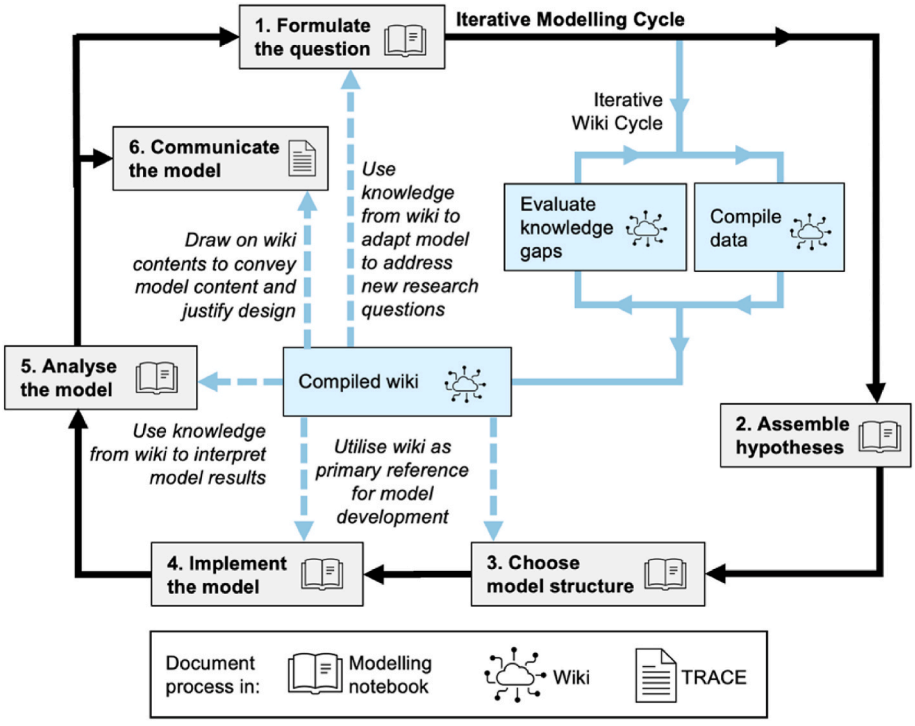

Fig. 3. Overview of the SES wiki approach and interface with iterative modelling cycle and documentation processes (Source: Authors).

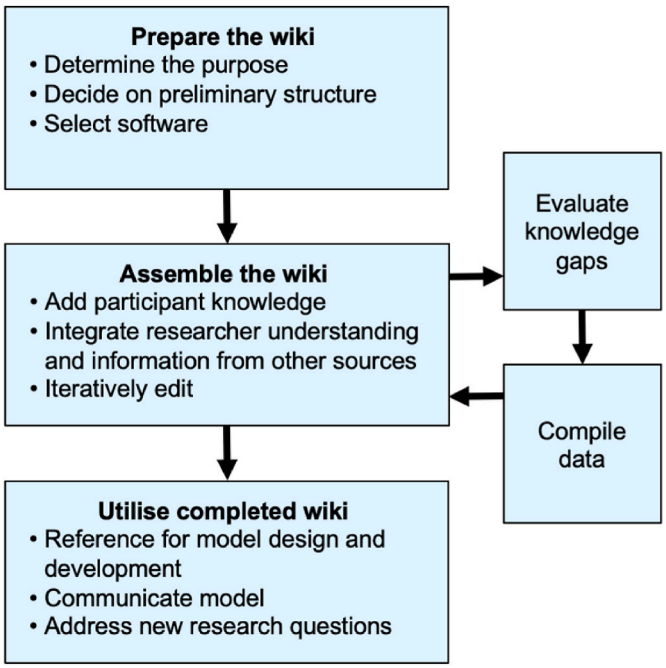

Fig. 4. Recommended stages and processes of the SES wiki approach (Source: Authors).

that it can be challenging to set up when used for the first time, long-term data storage can be complicated by reliance on third party software, there are data security and privacy issues to consider, and – in many instances – software is not designed for offline use. With regard to the later point, readers are directed to the distinction between wikis that use local flat file versus SQL-enabled databases.

Where circumstances do not allow for use of purpose-made wiki software, an offline quasi-wiki can be developed using word processing software – an approach we used for our Nepal wiki. Relative to specialist wiki software, this can be more labour-intensive as word processing software is not designed with enduring change and authorship tracking in mind (Perkel, 2016). Each contribution will need to be manually tagged with an author ID and other relevant metadata, and copies will need to be regularly saved as the wiki evolves. Although such an approach requires diligence, word documents are relatively simple to use, can still use hyperlinks to connect topic pages, and can be easily saved as PDFs – advantageous for sharing and long-term archiving. Note-taking software like OneNote and Notion represent another potentially powerful alternative. A run-through of typical data in a role-play of fieldwork during the software identification process is likely to be helpful in discovering potential usability issues.

We recommend that wikis be set up ahead of fieldwork so that they are ready to be used at the outset of data collection. Optionally, once the provisional topic pages have been created, researchers can populate them with their pre-fieldwork knowledge as well as identifying gaps in knowledge. This can help provide context to what is subsequently seen at field sites, aiding interpretation, allowing sanity tests, and flagging matters that should be probed. This process may also reveal additional topics that could be worth considering.

4.2. Assembling the wiki

4.2.1. Draw on participant knowledge

Wikis are designed to facilitate knowledge co-creation and therefore are ideal for participatory research. Participants can be recruited to write content and make edits themselves if they are literate, or the process can be facilitated by members of the research team asking questions and transcribing the responses. We recommend recruiting a diverse set of participants to maximise the perspectives and experiences drawn upon, though actively seeking out eloquent participants is pragmatic, given the nature of the task. Participants should be briefed on the purpose of the wiki and the topic areas on which their inputs are sought at the outset (Majchrzak et al., 2013), and appropriate consent should be obtained before they commence work. Given the time-consuming, multi-day nature of developing wikis, we also suggest that researchers consider remunerating participants at a locally appropriate rate.

Some coaching from the research team may be needed at the outset, with less guidance being required over time. Emphasising the desirability of detailed, algorithmic explanations of processes and decision making, and asking participants to provide numerical values where possible, is important from a modelling perspective. Flagging choices relating to the expenditure of time and resources whenever they arise should be encouraged too. They should also be asked to clearly flag uncertainty and variability to ensure researchers are mindful of this during the modelling stages.

To fully exploit the benefits of the wiki approach, we recommend encouraging participants to propose topics that they personally perceive as important in relation to the overall research purpose. More generally, we suggest that researchers make a concerted effort to create enabling conditions for participants to feel empowered. This should help maximise the breadth and depth of information elicited and make the process more fulfilling for participants.

Basic information on each of the participants and the circumstances of their involvement (e.g., age, gender, time, date, and location) should be recorded separately from the wiki (taking account of any local personal data protection requirements) and a means of tracking their individual contributions should be determined if this is not being logged automatically by wiki software. For example, each author can be assigned a unique code that can be appended to each of their contributions.

We recommend initially compiling the wiki in the local language if participants are literate. This allows them to write contributions and interrogate content directly, strengthening their sense of ownership over the process. The contents can be translated later if necessary. Where researchers are not fluent in the local language, this may temporarily compromise their capacity for oversight, so recruiting an able researcher assistant or translator to mediate the process will be vital.

4.2.2. Integrate researcher understanding and information from other sources

Researchers can also write content for the wiki, drawing on knowledge that they have gleaned from literature, other research exercises, informal discussions, and their own observations. Even knowledge that would typically be held tacitly can be worth documenting as it helps with recall and enables others to make sense of the information at a later stage. That said, we recognise that there are practical limits to the amount of knowledge that can be documented. That some knowledge will remain tacit is unavoidable, but the wiki approach at least offers a way to capture some knowledge that would otherwise only be held tacitly, enabling it to be documented in a formal and transparent manner. If researchers do engage in the authorship process, they should cite the origin of the insights, ensure that their contributions can be distinguished from those of other participants, and discuss any potentially sensitive topics with appropriate caution. We also recommend allowing participants the opportunity to critique these contributions, which may require translating them. This can help validate researcher interpretations and respects the spirit of co-creation that is central to the wiki concept. Ideally, researchers will refrain from personally authoring substantial amounts of content until participants have finished making the bulk of their contributions so that participant voices are prioritised.

4.2.3. Iteratively edit

As knowledge is added to the wiki, continuous editing will be required to ensure that the contents are kept clear and coherent. The aim

should be for each topic page to be written in a relatively parsimonious fashion, so regular filtering and pruning is important (Markus, 2001). As the topic articles are reviewed, content that is deemed to be below standard (e.g., insufficiently informative, contradictory, or unclear) should be flagged for attention should it not be possible to resolve immediately (Mietchen et al., 2011). We envisage that researchers lead the editing process, but participants can also assist. Empowering them to do so will allow researcher contributions to be validated and help with identifying any misinterpretations.

When contradictory or contested entries are identified, researchers have several options open to them. They could consult the original contributors, seek the views of additional parties, accept that there is legitimate ambiguity, or act as an arbiter themselves if they believe they have sufficient evidence to do so. Where views cannot be reconciled among all parties, a note should be added stating this. As Eitzel (2021) has argued, differences in knowledge need not always be viewed as problematic from a research perspective. Modelling enables the implications of contrasting perspectives to be explored and this can lead to valuable insights about systems that would not have been gleaned if differences in knowledge were erased during data collection.

It may also be appropriate to restructure the wiki from time to time if this improves flow (Majchrzak et al., 2013). Besides determining the topics that merit inclusion, it is important to consider which merit a standalone page. If a topic requires only a cursory mention, it is best to incorporate it into a higher-level page that covers the topic and others closely associated with it. For example, trees and wildlife might be best discussed under the common heading of ecology, if they are not going to be individually addressed in detail. These decisions can be reviewed as fieldwork progresses and understanding develops.

All knowledge collection will involve some degree of classification and associated decision making and filtering. In SES studies, this would ideally be a collaborative process which balances and reflects on the overlaps and differences between scientific-based and community-based means of understanding the world. The latter may not map perfectly onto formal scientific frameworks, but it is often in the mismatch between world views that the most crucial insights reside. It is therefore important that the structuring is responsive to community input, and that power structures do not compel a community to bend its worldview to fit academic paradigms.

4.3. Developing the model

The process of compiling the wiki can often generate insights that were not considered or anticipated during initial research design. It can therefore be useful to pause and reflect on what has been learned before commencing model development. The modular structure of the wiki can potentially provide inspiration for the design of the model structure, and links between topics in the wiki can help in identifying and understanding interconnections that merit consideration in the model design.

During model development, the wiki can act as a single common reference point for those involved in designing the model. As information is grouped in an intuitive, structured way, it should simplify the process of locating details as they are required. Wikis and SES models have a similar structural logic: they partially decompose systems, while recognising that important linkages between components remain (Ostrom, 2007; Wikipedia, 2016). Consequently, the knowledge contained in SES wikis will often map neatly onto SES models. They are in many respects proto-models in and of themselves – blueprints that can guide design, strongly rooted in the empirical reality of field sites. Wikis can also facilitate researchers who seek to take a pattern-oriented modelling (POM) approach (Grimm et al., 1996). POM involves identifying multiple SES features that can potentially be matched against when calibrating models and testing different configurations (Grimm et al., 2005), something that is not usually possible when data collection is narrow in scope but may be possible with wide-ranging data contained from an SES wiki. If sufficiently information rich, the wiki can furthermore be used by researchers to saturate themselves in the details of a study site and to take something akin to a grounded theory approach to the modelling process.

4.4. Communicating the model

The wiki, or extracts from it, can be published alongside model code and descriptions to provide background as well as rationale for key modelling decisions. However, before publishing either the wiki or extracts, it is important to consider whether participants could potentially be identified from the detailed information contained. Unlike many interviews, focus groups, or ethnographic studies, the information contained in a wiki is intentionally wide ranging and comprehensive, which increases the likelihood of participants' anonymity being compromised if viewed in its entirety, even if the wiki is written in a general, summary tone. If intending to make the entire wiki publicly available alongside the model, it is advisable to consider the anonymity of participants when writing articles from the outset rather than trying to retrospectively anonymise the entire wiki, as this could require a considerable amount of work. For example, articles could be written in such a way as to remove references to particulars and enumerate in ranges rather than specific values to obscure the identities of specific settings or individuals.

One flexible approach to managing anonymity when sharing the wiki is to tag topic pages - or even sections within topic pages - with different levels of shareability. Some topic pages may not contain any potentially identifying or sensitive information and can be shared publicly without issues, while others may need to be edited first. For certain topic pages, it may be necessary to restrict their viewing to just within the research team, or with other researchers subject to request. An alternative to sharing the wiki itself is to include excerpts from, or summaries of, wiki articles in other research outputs – a route that reduces dilemmas around how to handle sensitive information and which will also make the contents more practical for readers to digest.

Ideally, wikis or wiki extracts would be converted to a stable document format and stored in a permanent archive so that their availability will be assured in the long run (Perkel, 2016). For example, they could be stored along with model code in the CoMSES Net Computational Model Library (https://www.comses.net/codebases/) (Rollins et al., 2014). Aside from anonymisation and desensitisation, we suggest that researchers not worry much about finessing the contents of the wiki unless they have the time, resources, and desire to do so.

4.5. Extending the model and reusing knowledge

The knowledge contained in SES wikis could be of value to studies other than those that originally prompted their creation (Easterbrook, 2014; White et al., 2013). Wikis could be used to adapt models to address additional research questions, or to contribute to wholly different studies. For any of this to occur, firstly, the writing must be unambiguous, allowing future selves and other researchers to make sense of it without revisiting field sites. Secondly, the content must be sufficiently broad and comprehensive to allow new questions to be addressed. Finally, wikis need to be made accessible and other researchers need to be aware of their existence (Van Tuyl and Whitmire, 2016). Where wikis (or extracts of wikis) are suitable for public sharing, it is preferable to store them in topically appropriate public archives, as discussed in *Section 4.4*, accompanied by detailed descriptions of their contents and generous reuse licenses (Janssen, 2017; White et al., 2013).

5. Discussion

We have proposed wikis as an approach for managing case study knowledge for SES modelling projects, presented our Nepal field site wiki as an example of the approach in action, and offered guidance as to how they could be most effectively built and employed. In this section,

we critically evaluate the opportunities and challenges of the wiki approach as they apply across the phases of empirically driven model-based research outlined in Fig. 3. We draw on our own experience of using it to construct an ABM of a mountain community to show how the SES wiki approach can be both practical and effective in the appropriate context but also to demonstrate the real-world difficulties of implementation. We focus on four main issues: the time demands required to produce a wiki, how participants can be empowered in the process of creating a wiki, what software to use, and considerations around sharing an SES wiki.

5.1. Time demands

Time demands are often cited as a reason why the ODD protocol and TRACE framework are not utilised more frequently (Grimm et al., 2014; Müller et al., 2013). SES wikis are also time consuming, both for participants and researchers. However, a substantial upside of the wiki approach is that it improves modelling efficiency. Assuming that conflicts and inconsistencies in the wiki were resolved during the data collection, the knowledge contained should already be coherent by the time modelling begins, allowing researchers to focus on modelling judgements rather than knowledge reconciliation. In contrast, where the wiki approach is not used and where conflicting information has not been addressed in the field, the modelling process is complicated by the need to select between sources or determine compromise solutions – something that can greatly hinder progress. Wikis also make it less likely that knowledge gaps will be encountered during modelling, reducing the potential need for costly additional data collection later. Furthermore, SES wikis can help with issues of institutional memory in the case of projects where there is staff turnover or if the person developing the model is different from the fieldwork researchers. Indeed, wikis are often used in the corporate world for such purposes (Ashkenas, 2013). They offer a ready means for third parties to absorb and make sense of study site knowledge, reducing the need for time consuming briefings and exchanges.

Adapting existing models to address new research questions is an efficient way to conduct science (Laatabi et al., 2018, para. 1.2). However, code is rarely reused at present as there is often insufficient knowledge about a case study site to reconfigure the model in an empirically supported fashion (Janssen, 2017; Janssen et al., 2020; Müller et al., 2014). By providing knowledge on a near-comprehensive range of topics, wikis can facilitate the retrospective adaptation of empirically grounded SES models, obviating the need for fresh fieldwork and greatly improving the resource efficiency of the SES modelling field. This increases the value derived from the generosity of research participants and accelerates the pace of disciplinary progress (Cragin et al., 2010; Janssen, 2017; Martone, 2014). However, there are risks in trying to make wikis exhaustive in an effort to maximise potential research openings. Compiling information without limits can be a substantial time sink and realistically there are limits to the number of research questions that any given case study will productively lend itself to. It is also difficult to anticipate the information needs of yet-to-be fleshed out research ideas. However comprehensive researchers try to be, there will be topics that are missed that will impose constraints on future research. When we extended our model to address questions around food security, for example, we recognised there were gaps in our knowledge that we would have to fill using information from secondary source.

5.2. Empowering participants

Increasing research subject agency is often spoken of as a desirable objective in SES modelling studies (e.g., Becu et al., 2006; Naivinit et al., 2010; Steger et al., 2021), yet the options for doing this remain limited (Voinov and Bousquet, 2010). The wiki development process can facilitate direct authorship and scrutiny of SES knowledge by research subjects, imbuing participants with substantial agency and fostering a sense of research ownership among study communities. This can redress some of the power imbalances inherent in fieldwork, increase the likelihood of recommendations being heeded, and lessen the likelihood that important aspects of the field site are overlooked by researchers (Darroch and Giles, 2014; Pain and Kindon, 2007; Schensul et al., 2015; Voinov and Bousquet, 2010). For agent-based modellers in particular, the opportunity to view a SES through the eyes of real-world agents is immensely valuable as it offers direct insights into agent decision making and behaviour, facilitating their recreation in code.

While the benefits of co-production approaches are substantial, we also experienced some challenges which demonstrate the need for careful selection and guidance of participants, careful expectation management, and strong people skills. For example, we found it difficult to find participants who had sufficient free time to take part - particularly for older generations, as they tended to have more work commitments. It was also sometimes difficult to elicit information in a suitable format for the wiki, as some villagers at the field site in Nepal, particularly those with very little formal education, tended to address topics in narrative form which was difficult to package into thematic pages. Difficulties were also encountered with acquiring information at the desired level of detail and progressing through themes at a productive rate. Literacy, however, was not a barrier as we were able to take dictation where required, allowing us to avoid excluding the older, less literate generations.

The differing willingness and capacity of people to engage can be problematic from a representation perspective as literacy levels and communication styles can be closely linked with ethnicity, caste, sex, age, and socio-economic backgrounds (Laws et al., 2013). One way of dealing with this, which our participants proposed, is to allow them to engage with other community members when they encounter gaps in their own knowledge. Sensitive oversight is required to ensure that those recruited to complete the wiki are not (advertently or inadvertently) providing biased information or failing to include differing viewpoints and opinions. As participants will have access to content written by others, it is also critical that the sensitivity of information in the wiki be monitored to avoid privacy violations or other potential harms (Damianakis and Woodford, 2012). Researchers must also be aware of the risk of social biases, culturally and politically motivated edits, and peer pressure influencing the development of the wiki, especially in relation to sensitive topics. Enforcing some degree of verifiability standards will be particularly critical wherever there is elevated risk of such influences.

5.3. Wiki software

There are a number of practical issues with wiki software that will complicate the development of SES wikis in certain contexts. In our case, we encountered significant challenges with internet connectivity and power availability during fieldwork (Roxburgh, 2019; Roxburgh et al., 2021). Mobile internet connections were unreliable, and we were frequently unable to recharge phones and laptops due to power outages. This made conventional web-based wiki software impractical to use. Word processing software proved to be an adequate substitute once we figured out procedures for authorship and edit tracking, but it did demand fastidiousness to keep on top of this tracking and we did not always get it right. Purpose designed wiki software offers automated tracking which relieves this burden and reduces the likelihood of errors. This is something we view as a substantial strength in light of our experiences, but it is more complicated to initially setup.

The power outages occasionally prevented us from running electronic devices – a hindrance regardless of the approach used. We overcame this by compiling notes on paper and then typing them up once power was available again. This worked reasonably when the outages were limited to a few hours, but we suspect longer periods without power would have proved seriously problematic as we found it was valuable to be able to refer back to existing content as we worked. Potential users should take these issues into consideration when deciding

how to proceed.

5.4. Sharing wikis

The breadth and comprehensiveness of wikis make them powerful research tools but can also – in certain situations – limit the extent to which they can be published and shared. For example, our wiki described the lives and livelihoods of a Nepalese mountain community in minute detail. While extracts of the Nepal wiki could be shared without issue, to publish it in its entirety could potentially provide enough information to identify the village and its members. This is something we could not risk from an ethics standpoint. In other cases, the risks to anonymity may be less; it will depend on the idiosyncrasies of the field site, the kinds of data collected, and how they are recorded in the wiki. This presents something of dilemma. On the one hand, the detailed nature of SES wikis could make them valuable knowledge resources if shared. On the other hand, their detailed nature means great caution needs to be taken to ensure they cannot be misused, and that the anonymity of participants is respected. Starting from the principle that we should, as a research community, aspire to share data to the greatest extent possible (McNutt, 2014; Schofield et al., 2009), we suggest users publish a carefully edited version of their wikis, leaving in as much information as possible, while addressing possible issues around anonymity and noting the nature of any details that have been removed. Should other researchers wish to access the redacted data, further discussion can be had around how that might be done in an ethically sound way.

6. Conclusion

Collaborative ethnography has significant advantages. As well as respecting communities, welcoming and supporting their agency, collaborative work is more likely to build a fuller understanding of community dynamics; is likely to bring a richer understanding and commitment to research within the communities with less experience of science; and represents an opportunity for two-way flow and stimulation of community enhancing ideas. Nevertheless, collaboration brings issues with it of knowledge management, with older techniques of complicated, scientist-and-hypothesis driven, field logging failing to provide accessible or suitably structured toolsets and therefore to maximise knowledge elicitation. In this paper, we have suggested wikis provide a more suitable mechanism for data collation, structuring, and understanding. In particular, they may aid in the process of structuring and mapping the understanding of systems such as to make the production of disaggregate social, environmental, and economic models more robust and complete. We have additionally reflected on our use of such techniques when engaged in fieldwork and subsequently modelling a rural highland community in Nepal.

Wikis are not, by any means, a full solution to the issues of collaborative data acquisition. There are a number of facets of human communication and lived experience they can represent only imperfectly: purposeful ambiguity in relationships; the strength of connections between concepts; spatial links and dynamic changes, for example. Nevertheless, they represent a considerable step forward as a knowledge representation system for field studies, not only in terms of the collaborative collation of data, but also through their opening up of the collaborative structuring of knowledge and the subsequent analysis and use of those structures. As such, we would hope that this paper goes some way to encouraging field scientists, especially those collecting data for disaggregate modelling, to utilise wikis in field practice.

Author contributions

Nicholas Roxburgh: Conceptualization, Methodology, Investigation, Data curation, Visualization, Writing - original draft, Writing - review & editing. **Lindsay C. Stringer:** Conceptualization, Methodology, Writing - review & editing. **Andrew J. Evans:** Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing. **Tim G. Williams:** Methodology, Writing - review & editing. **Birgit Müller:** Methodology, Writing - review & editing.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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References

Adhikari, J., 2000. Decisions for Survival: Farm Management Strategies in the Middle Hills of Nepal. Adroit Publishers, Delhi.

Ashkenas, R., 2013. How to preserve institutional knowledge [WWW Document]. Harv. Bus. Rev. URL. https://hbr.org/2013/03/how-to-preserve-institutional, 5.20.21.

Baumeister, J., Reutelshoefer, J., Nadrowsk, K., Misok, A., 2007. Using knowledge wikis to support scientific communities. In: LWA 2007. Halle.

Becu, N., Sangkapitux, C., Neef, A., Kitchaicharoen, J., Elstner, P., 2006. Participatory simulation sessions to support collective decision: the case of water allocation between a Thai and a Hmong village in northern Thailand. In: Proceedings of the International Symposium "Towards Sustainable Livelihoods and Ecosystems in Moutainous Regions". Chiang Mai, Thailand, pp. 7–9.

Cragin, M.H., Palmer, C.L., Carlson, J.R., Witt, M., 2010. Data sharing, small science and institutional repositories. Philos. Trans. R. Soc. A Math. Phys. Eng. Sci. 368 https://doi.org/10.1098/rsta.2010.0165, 4023–3038.

Dai, L., Tian, M., Wu, J., Xiao, J., Wang, X., Townsend, J.P., Zhang, Z., 2013. AuthorReward: increasing community curation in biological knowledge wikis through automated authorship quantification. Bioinformatics 29, 1837–1839. https://doi.org/10.1093/bioinformatics/btt284.

Damianakis, T., Woodford, M.R., 2012. Qualitative research with small connected communities: generating new knowledge while upholding research ethics. Qual. Health Res. 22, 708–718. https://doi.org/10.1177/1049732311431444.

Darroch, F., Giles, A., 2014. Decolonizing health research: community-based participatory research and postcolonial feminist theory. Can. J. Action Res. 15, 22–36. https://doi.org/10.33524/cjar.v15i3.155.

Easterbrook, S.M., 2014. Open code for open science? Nat. Geosci. 7, 779–781. https://doi.org/10.1038/ngeo2283.

Eitzel, M.V., 2021. A modeler's manifesto: synthesizing modeling best practices with social science frameworks to support critical approaches to data science. Res. Ideas Outcomes 7, e71553. https://doi.org/10.3897/rio.7.e71553.

Epstein, J.M., 2006. Generative Social Science: Studies in Agent-Based Computational Modeling. Princeton University Press, Princeton.

Fricke, T.E., 1993. Himalayan Households: Tamang Demography and Domestic Processes. Pilgrims Publishing, Varanasi.

Grimm, V., Augusiak, J., Focks, A., Frank, B.M., Gabsi, F., Johnston, A.S., Liu, C., Martin, B.T., Meli, M., Radchuk, V., Thorbek, P., 2014. Towards better modelling and decision support: documenting model development, testing, and analysis using TRACE. Ecol. Model. 280, 129–139. https://doi.org/10.1016/j.ecolmodel.2014.01.018.

Grimm, V., Berger, U., Bastiansen, F., Eliassen, S., Ginot, V., Giske, J., Goss-Custard, J., Grand, T., Heinz, S.K., Huse, G., 2006. A standard protocol for describing individual-based and agent-based models. Ecol. Model. 198, 115–126.

Grimm, V., Berger, U., DeAngelis, D.L., Polhill, J.G., Giske, J., Railsback, S.F., 2010. The ODD protocol: a review and first update. Ecol. Model. 221, 2760–2768. https://doi.org/10.1016/j.ecolmodel.2010.08.019.

Grimm, V., Frank, K., Jeltsch, F., Brandl, R., Uchmański, J., Wissel, C., 1996. Pattern-oriented modelling in population ecology. Sci. Total Environ. 183, 151–166. https://doi.org/10.1016/0048-9697(95)04966-5.

Grimm, V., Railsback, S.F., Vincenot, C.E., Berger, U., Gallagher, C., DeAngelis, D.L., Edmonds, B., Ge, J., Giske, J., Groeneveld, J., Johnston, A.S., 2020. The ODD protocol for describing agent-based and other simulation models: a second update to improve clarity, replication, and structural realism. J. Artif. Soc. Soc. Simulat. 23.

Grimm, V., Revilla, E., Berger, U., Jeltsch, F., Mooij, W.M., Railsback, S.F., Thulke, H.H., Weiner, J., Wiegand, T., DeAngelis, D.L., 2005. Pattern-oriented modeling of agent-based complex systems: lessons from ecology. Sci (80-.) 310, 987–991.

Janssen, M.A., 2017. The practice of archiving model code of agent- based models. J. Artif. Soc. Soc. Simulat. 20, 2. https://doi.org/10.18564/jasss.3317.

Janssen, M.A., Ostrom, E., 2006. Empirically based, agent-based models. Ecol. Soc. 11, 37.

Janssen, M.A., Pritchard, C., Lee, A., 2020. On code sharing and model documentation of published individual and agent-based models. Environ. Model. Software 134, 104873. https://doi.org/10.1016/j.envsoft.2020.104873.

Laatabi, A., Marilleau, N., Nguyen-Huu, T., Hbid, H., Babram, M.A., 2018. ODD+2D: an ODD based protocol for mapping data to empirical ABMs. J. Artif. Soc. Soc. Simulat. 21, 9.

Lange, C., 2007. Towards scientific collaboration in a semantic wiki. In: Bridging the Gap between Semantic Web and Web 2.0 (SemNet 2007). Innsbruck, Austria, pp. 119–126.

Laws, S., Harper, C., Jones, N., Marcus, R., 2013. Research for Development: A Practical Guide. Sage Publications, London.

Linstädter, A., Kuhn, A., Naumann, C., Rasch, S., Sandhage-Hofmann, A., Amelung, W., Jordaan, J., Du Preez, C.C., Bollig, M., 2016. Assessing the resilience of a real-world social-ecological system: lessons from a multidisciplinary evaluation of a South African pastoral system. Ecol. Soc. 21 https://doi.org/10.5751/ES-08737-210335.

Majchrzak, A., Wagner, C., Yates, D., 2013. The impact of shaping on knowledge reuse for organizational improvement with wikis. MIS Q. 37, 455–469.

Markus, L.M., 2001. Toward a theory of knowledge reuse: types of knowledge reuse situations and factors in reuse success. J. Manag. Inf. Syst. 18, 57–93. https://doi.org/10.1080/07421222.2001.11045671.

Martone, M.E., 2014. Brain and Behavior: we want you to share your data. Brain Behav 4, 1–3. https://doi.org/10.1002/brb3.192.

McNutt, M., 2014. Journals unite for reproducibility. Science 84 346, 679. https://doi.org/10.1126/science.aaa1724.

Mietchen, D., Hagedorn, G., Förstner, K.U., Kubke, M.F., Koltzenburg, C., Hahnel, M., Penev, L., 2011. Wikis in scholarly publishing. Inf. Serv. Use 31, 53–59. https://doi.org/10.3233/ISU-2011-0621.

Miller, C.J., 1990. Decision Making in Village Nepal. Sahayogi Press.

Momsen, J.H., 2006. Women, men and fieldwork: gender relations and power structures. In: Desai, V., Potter, R.B. (Eds.), Doing Development Research. Sage Publications, London, pp. 44–51. https://doi.org/10.4135/9781849208925 n5.

Müller, B., Balbi, S., Buchmann, C.M., De Sousa, L., Dressler, G., Groeneveld, J., Klassert, C.J., Le, Q.B., Millington, J.D., Nolzen, H., Parker, D.C., 2014. Standardised and transparent model descriptions for agent-based models: current status and prospects. Environ. Model. Software 55, 156–163. https://doi.org/10.1016/j.envsoft.2014.01.029.

Müller, B., Bohn, F., Dreßler, G., Groeneveld, J., Klassert, C., Martin, R., Schlüter, M., Schulze, J., Weise, H., Schwarz, N., 2013. Describing human decisions in agent-based models–ODD+ D, an extension of the ODD protocol. Environ. Model. Software 48, 37–48. https://doi.org/10.1016/j.envsoft.2013.06.003.

Naivinit, W., Le Page, C., Trébuil, G., Gajaseni, N., 2010. Participatory agent-based modeling and simulation of rice production and labor migrations in Northeast Thailand. Environ. Model. Software 25, 1345–1358. https://doi.org/10.1016/j.envsoft.2010.01.012.

Ostrom, E., 2007. A diagnostic approach for going beyond panaceas. Proc. Natl. Acad. Sci. USA 104, 15181–15187. https://doi.org/10.1073/pnas.0702288104.

Pain, R., Kindon, S., 2007. Participatory geographies. Environ. Plan. A Econ. Sp. 39, 2807–2812. https://doi.org/10.1068/a39347.

Perkel, J., 2016. Democratic databases: science on GitHub. Nature 538, 127–128. https://doi.org/10.1038/538127a.

Piccoli, G., Ahmad, R., Ives, B., 2000. Knowledge management in academia: a proposed framework. Inf. Technol. Manag. 1, 229–245. https://doi.org/10.1023/A:1019129226227.

Polhill, J.G., Filatova, T., Schlüter, M., Voinov, A., 2016. Modelling systemic change in coupled socio-environmental systems. Environ. Model. Software 75, 318–332. https://doi.org/10.1016/j.envsoft.2015.10.017.

Polhill, J.G., Ge, J., Hare, M.P., Matthews, K.B., Gimona, A., Salt, D., Yeluripati, J., 2019. Crossing the chasm: a 'tube-map' for agent-based social simulation of policy scenarios in spatially-distributed systems. GeoInformatica 23, 169–199. https://doi.org/10.1007/s10707-018-00340-z.

Railsback, S.F., Grimm, V., 2012. Agent-based and Individual-Based Modeling: A Practical Introduction. Princeton University Press, Princeton.

Rollins, N.D., Barton, C.M., Bergin, S., Janssen, M.A., Lee, A., 2014. A Computational Model Library for publishing model documentation and code. Environ. Model. Software 61, 59–64. https://doi.org/10.1016/j.envsoft.2014.06.022.

Roxburgh, N., 2019. Modelling the Combinatory Impact of Stressors on Mountain Communities. University of Leeds.

Roxburgh, N., Stringer, L.C., Evans, A., Malleson, N., Heppenstall, A.J., 2021. Impacts of multiple stressors on mountain communities: insights from an agent-based model of a Nepalese village. Global Environ. Change 66, 102203. https://doi.org/10.1016/j.gloenvcha.2020.102203.

Sauer, I.M., Bialek, D., Efimova, E., Schwartlander, R., Pless, G., Neuhaus, P., 2005. Blogs" and "wikis" are valuable software tools for communication within research groups. Artif. Organs 29, 82–89. https://doi.org/10.1111/j.1525-1594.2004.29005.x.

Schensul, S.L., Schensul, J.J., Singer, M., Weeks, M., Brault, M., 2015. Participatory methods and community-based collaborations. In: Bernard, H.R., Gravlee, C.C. (Eds.), Handbook of Methods in Cultural Anthropology. Rowman and Littlefield, Lanham, p. 822.

Schmolke, A., Thorbek, P., DeAngelis, D.L., Grimm, V., 2010. Ecological models supporting environmental decision making: a strategy for the future. Trends Ecol. Evol. 25, 479–486. https://doi.org/10.1016/j.tree.2010.05.001.

Schofield, P.N., Bubela, T., Weaver, T., Portilla, L., Brown, S.D., Hancock, J.M., Einhorn, D., Tocchini-Valentini, G., de Angelis, M.H., Rosenthal, N., 2009. Post-publication sharing of data and tools. Nature 461, 171–173. https://doi.org/10.1038/461171a.

Smajgl, A., Brown, D.G., Valbuena, D., Huigen, M.G., 2011. Empirical characterisation of agent behaviours in socio-ecological systems. Environ. Model. Software 26, 837–844. https://doi.org/10.1016/j.envsoft.2011.02.011.

Steger, C., Hirsch, S., Cosgrove, C., Inman, S., Nost, E., Shinbrot, X., Thorn, J.P., Brown, D.G., Grêt-Regamey, A., Müller, B., Reid, R.S., 2021. Linking model design and application for transdisciplinary approaches in social-ecological systems. Global Environ. Change 66, 1–14. https://doi.org/10.1016/j.gloenvcha.2020.102201.

Van Tuyl, S., Whitmire, A.L., 2016. Water, water, everywhere: defining and assessing data sharing in academia. PLoS One 11, e0147942. https://doi.org/10.1371/journal.pone.0147942.

Voinov, A., Bousquet, F., 2010. Modelling with stakeholders. Environ. Model. Software 25, 1268–1281. https://doi.org/10.1016/j.envsoft.2010.03.007.

Wagner, C., 2004. Wiki: a technology for conversational knowledge management and group collaboration. Commun. Assoc. Inf. Syst. 13, 265–289. https://doi.org/10.17705/1CAIS.01319.

Whelpton, J., 2005. A History of Nepal. Cambridge University Press, Cambridge.

White, E.P., Baldridge, E., Brym, Z.T., Locey, K.J., McGlinn, D.J., Supp, S.R., 2013. Nine simple ways to make it easier to (re)use your data. Ideas Ecol. Evol. 6, 1–10.

Wikipedia, 2020a. Wikipedia:Verifiability [WWW Document]. Wikipedia. URL. https://en.wikipedia.org/wiki/Wikipedia:Verifiability, 10.5.20.

Wikipedia, 2020b. Wiki Software. Wikipedia [WWW Document].

Wikipedia, 2016. Wiki [WWW Document]. URL. https://en.wikipedia.org/wiki/Wiki, 7.28.16.