Good Practices for Sharing Ecological Models

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As the fields of ecology and conservation biology increasingly rely on models to address pertinent questions, there has been greater sharing of models among scientists. However, many models lack comprehensive documentation, especially in a format that is easy to use and to understand. Also, modelers lack a framework they can use when evaluating a model for its potential use. Here we outline how ecologists and conservation biologists can begin to establish a culture of good practice for model sharing. We offer suggestions on how model developers, model users, user communities, and journal editors can contribute to the appropriate sharing of ecological models.

Keywords: ecological modeling, methodology for model sharing, model evaluation, expert systems

Ecologists and conservation biologists increasingly rely on computer models and software (hereafter referred to collectively as "models") to address pertinent questions. For instance, population biologists frequently use the VORTEX model (*www.vortex9.org/vortex.html*) for population viability analyses, while the JABOWA (Botkin et al. 1972) and FORET (Shugart and West 1977) models have undergone numerous transformations to address landscape fragmentation research questions in different forest systems (Malanson and Armstrong 1996, Easterling et al. 2001). Today, many ecologists are not only developing their own models but also taking advantage of preexisting models for their research. Although such practices have great potential for improving ecological understanding and conservation, there are problems associated with this trend. Models rarely include clearly written manuals in which basic information about the model (i.e., objectives, assumptions, data requirements, scale, output, programming language) is explicitly outlined. Without such documentation, potential users are limited in their ability to understand the intricacies of a model, and therefore may use it inappropriately. In addition, modelers lack the methodology to evaluate a potential model for its suitability for a particular situation. Because of these issues, the community of model builders and users should place greater emphasis on using models appropriately. If ecologists had a methodology for evaluating the appropriateness of an existing model, misuse could be drastically reduced, and peer-reviewed journals would have a recognized standard for new models presented in papers as well as a justification for the use of other people's models.

Evidence from the field

To determine the extent of model sharing in ecology, we surveyed the 2004–2005 issues of *Ecological Modelling*. We found that about one-third of the researchers either used or modified models developed by other ecologists. Interestingly, this third consisted predominantly of models with limited documentation, or unsupported models intended for one-time use, rather than well-supported commercial or noncommercial packages. To investigate how frequently ecologists use well-documented, commercially available models, we classified models published in the 2004–2005 issues of *Ecological Modelling* and the 2004 issues of *Ecological Applications* into three categories based on usage and available support. Models were divided into these categories according to their online availability and the context of the model in publication. The categories are as follows:

Category 1: Publicly accessible and well-supported models. These are models such as the aforementioned VORTEX model, CENTURY (*www.nrel.colostate.edu/projects/century5*), and RAMAS (*www.ramas.com/software.htm*), and, to a lesser extent, JABOWA (Botkin et al. 1972) and FORET (Shugart and West 1977), which have all become part of the culture of ecology. These models are used frequently by ecologists, are commercially available or can be downloaded for free, and have one or more of the following criteria: extensive online documentation, extensive documentation available in print form, or multiple papers published using the model. If a

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Google search for a program did not reveal this information, then the program was not considered well supported.

Category 2: Published models with limited support and use. These are models that are shared by a limited community of ecologists and lack the extensive documentation of those models in category 1. These models either are published in the literature or are available online for download. They may have been manipulated or borrowed by other authors to expand on the use of a model, or developed by other authors as a piece of a more comprehensive model. Finally, new models were included in this category if they were obviously intended for others to use (e.g., described as "frameworks" or "templates" in the text). These models generally lack extensive support, although basic model information is usually available as part of a publication.

Category 3: One-time use models. These are models that are not obviously intended for use by others. They may be newly published models that are specific to a particular species or site. Many of these models are based on principles of logistic regression or growth, are GIS (geographic information system)-based models, or are simulations based on data. These models lack substantial support for other researchers using the model.

We determined that the models used in most papers fell into category 2 (32 percent) and category 3 (46 percent); only 22 percent of studies used publicly accessible and well-supported models (table 1).

We were also interested in common problems associated with model sharing. To obtain anecdotal information to motivate our discussion, we interviewed 10 graduate students in ecology- and conservation biology–related fields at the University of Minnesota. We asked students five questions:

1. What models or software are you using for your research (excluding statistical packages)?
2. How did you learn to use the model?
3. Do you know the assumptions of the model? Can you list some of them?
4. Have you had any problems using the model?
5. Is there anything you wish you had known about the model prior to using it?

We found that model misuse was frequent, and that many students were frustrated with the problem of how to use another scientist's model intelligently, especially when no formal documentation of the model was available. Students often admitted that they lacked a deep understanding of the model's objectives, assumptions, and limitations. In some cases, model users were in danger of choosing the wrong model for their needs (e.g., wrong scale, inappropriate assumptions, wrong objective). In others, model output was misinterpreted slightly or even profoundly. Although we don't assume that these graduate students are representative of all ecologists sharing models, we have no reason to believe that their experiences are unique.

The results of our surveys indicate that there need to be changes in how models are documented and shared. Here we suggest how a user should perform "due diligence" before using somebody else's model, and we outline some options that model developers, user communities, and journal editors can provide to encourage more appropriate use of models as research and management tools. We hope these practices will foster a culture in which there is transparency and consistency in the development, documentation, and sharing of models.

What the individual user can do

Ecological modeling still remains more of an art than a science (Getz 1998). Every ecological model both simplifies and caricatures reality; the art lies in choosing the appropriate simplifications. For every reality, there is a potentially infinite number of "model worlds" to represent that reality. For example, one population model might ignore all males, another might ignore disease, and a third might be spatially explicit but ignore age structure. As George Box (1979) once said, "All models are wrong but some are useful" (p. 202). The art of modeling and model sharing lies in designing a model world that is useful for the situation at hand.

Because every model world has to be designed for a specific purpose, one cannot make the decision to use someone else's model without first designing one's own model world and understanding how one intends to use the model. The user must also fully understand the model world behind the model intended for use, and how to put it to good use (whether or not it is a perfect match for the user's own model world). Model users will encounter different challenges for well-supported commercial packages than for models not intended for use by others. In the former, the model may be overly complex or overly general but may have comprehensive documentation, whereas the latter may be very specific to a particular system, may have objectives that are too strict to meet another modeler's needs, and may lack documentation. In either case, in comparing the developer's and user's model worlds, a number of questions should be considered. We propose the following questions for an initial evaluation of a model's fit to a user's needs. The two model worlds do not have to be identical in all respects, but any differences between them should be thoroughly explored.

Stage 1 assessment: Evaluating suitability

Question 1: What is the user's modeling objective, and is it congruent with the developer's objective? Sometimes differences in objectives can be accommodated through slight alterations of the model. In other cases, differences in objectives might require substantially different models. For example, Starfield (1997) discussed the design of three very different models of African buffalo (*Synceros caffer*) population dynamics, developed in response to three different

Table 1. Classification of computer models used in studies published in the 2004 issues of Ecological Applications *and the 2004–2005 issues of* Ecological Modelling.

Journal	Category 1: Publicly accessible and well-supported models (percentage)	Category 2: Published models with limited support and use (percentage)	Category 3: One-time use models (percentage)	Total number of papers surveyed
Ecological Modelling	55 (21)	86 (33)	120 (46)	261
Ecological Applications	24 (25)	27 (28)	45 (47)	96
Total	79 (22)	113 (32)	165 (46)	357

objectives. In the first case, the model objective was to project population size over 3 to 4 years, based on census data. This model required a subannual time step to account for seasonal effects while females were divided into annual cohorts. A constant sex ratio was assumed, and density dependence could be ignored. In the second model, the objective was to determine the long-term effect (over 50 to 100 years) of culling on population numbers. In this model, a one-year time step was used, sex and age structure were ignored, and population parameters were driven both by annual rainfall and by the size of the population. In the third model, the objective was to determine how to maximize the number of trophy bulls in a population. In this situation, age and sex structure were important, and males needed to be included explicitly. Even though all three models simulate the population dynamics of African buffalo, three different objectives resulted in model worlds that differed critically with regard to the resolution of time and population structure.

Question 2: What are the user's and developer's key assumptions, and are they compatible? The danger in using someone else's model can be likened to opening an attachment to an e-mail from a stranger—one can import "viruses" that undermine the logic of a modeling exercise. Looking at someone else's model world without first designing one's own can lead to acceptance of assumptions that are inappropriate for the study at hand. Seemingly innocuous assumptions might have consequences that disqualify the model in some circumstances but not in others. For instance, a population viability code might ignore social behavior; this might be a good assumption except in cases where social behavior affects the survival of the very young (as among lions and wolves).

If the developer's assumptions are too restrictive, the model should not be used without, at least, an evaluation of the impact of those assumptions. On the other hand, if the user's model world is less complex (in the sense of having more simplifying assumptions) than the developer's, then caution should be exercised in using a model that may consume effort and time, but not ultimately enlighten the user. Excess complexity in a model could well distract the user, lead to the collection of unnecessary data, prevent clear thinking, and make model output harder to interpret and present. In short, using a more complex model than necessary can be costly in terms of interpretability and understanding.

Question 3 (a): Do both model worlds have similar data needs? Subtle or even major differences may exist, both in the data required to use a particular model and in the type of data available to the user. Some models may incorporate more parameters than are necessary for the kind of analysis required by the user. If the model requires data that a user does not have and cannot estimate reasonably, then the user might feel compelled to invest time to conduct fieldwork or literature surveys to collect those data. In the example of African buffalo population models described above, one model requires data on both males and females, while the others ignore sex-specific information. The difference between the two approaches may seem inconsequential, but the difference in data requirements is substantial.

Question 3 (b): What kind of data resolution and quality is required? While the overall data needs may appear similar, it is essential for model users to pay attention to issues of resolution and quality. For instance, if a plant population model requires seed production data at the resolution of individual plants, will long-term averages be adequate for the user? Or are seasonal data needed, or information regarding variance among individuals or over time? The answer to these questions might be different depending on whether the model was applied to a species with mast seed production (i.e., a species that produces large crops of seeds every few years, so its average seed production is not representative of the extreme variability in seed production from year to year).

Question 4: Do both model worlds have compatible spatial and temporal scales of resolution? Some kinds of questions simply cannot be addressed if the model does not account for processes occurring at spatial or temporal scales of interest. In the seed production case mentioned above, if masting occurred on multiyear cycles, then a model that looks purely at average long-term growth trends would not have the facility to account for interannual variation and its impact on medium-term plant community structure. Similarly, a landscape-scale model looking at plant community diversity must consider factors like fire disturbance, whereas a patch model would focus more on small-scale factors such as shading and nitrogen competition.

ministic model would suffice is distracting and potentially confusing. On the other hand, certain questions can only be addressed by a model that includes appropriate stochastic elements. For example, when a plant growth model (which might be deterministic) is scaled up to address landscape-level questions on patch structure in prairies or forest, the scaled-up model should include stochastic events, such as forest gap formation through treefall, and the effects of fire or even tornadoes on patch formation.

Question 6: Does the output required by the two models match up? A stochastic model might calculate means and standard deviations when a probability distribution would be more useful. This is the case, for example, when the course of an epidemic depends on the load of "superspreaders" in the tail of a transmission distribution rather than on the variance in the number of individuals infected by each infective agent in the population (Getz and Lloyd-Smith 2005). If the model does not produce the required output, then either the question being asked must be changed or the model must be modified. The former should not be rejected out of hand: It may represent an acceptable first step toward getting some valuable insights into the behavior of a system, even though it may not answer the precise question at hand.

Question 7: Is the code accessible and easy to alter? How one reacts to discrepancies between model worlds depends partly on how easy it is to modify code. For example, is it possible to switch out or replace a routine that is irrelevant? Or, as in the previous stochastic model example, can the output be modified? If the code is readily accessible, then considerable time and effort may be saved in modifying an existing model rather than trying to develop a new model from scratch.

Stage 2 assessment: Verifying suitability

Once the questions above have been addressed to assess whether a potential model is appropriate for use, and some preliminary runs of the model have been made, the following additional steps are recommended:

Step 1: Users should construct their own very simple model and compare the results with the more complex model they have adopted, to check that major discrepancies do not exist in the model predictions. The user needs to understand the source of all moderate discrepancies. For example, general predictions of population trends should be the same irrespective of whether one model considers age structure and the other does not. However, short-term responses may be quite different if the initial population consists primarily of immature individuals.

Step 2: A thorough sensitivity analysis is essential. It provides an understanding of a model's sensitivity to alternative scenarios or management actions as well as alternative parameter values (Beres and Hawkins 2001). A sensitivity analysis provides a quick sense of how the model performs and what its limitations might be.

Step 3: As part of the sensitivity analysis, users should push the model beyond its breaking point—that is, to the point where the results could not possibly bear any resemblance to the behavior of the system they model. Since every model is designed for a purpose, it applies to a restricted set of conditions or parameter values. It is important for a potential user to know how well the model performs at the outer edges of those conditions, or how quickly its performance deteriorates as the model's use deviates from its stated purpose.

What the model developer can do

Model developers sometimes, but not always, support their models with a user manual. The quality of user manuals varies; some are poorly written or fail to mention important facts about the model. They are often written entirely from the viewpoint of those who developed the model, in the sense of "This is what we did," rather than "This is how you might be able to use it." A format or structure that requires the model developer to address how others might or might not be able to use a model is necessary to ensure that a likely user can understand the model's potential and limitations. A small, front-end expert system, written by the model developer for the potential user, offers one way of developing such a structure.

Expert systems are question-and-answer-based computer systems based on artificial intelligence concepts developed in the 1980s (e.g., see Plant and Stone 1991 for an agricultural application). Expert systems can be used to query a potential user to determine whether there is a proper fit between the model and the user. The developer cannot be expected to anticipate the needs of every potential user, but should make all potential users fully aware of the model's assumptions and key components.

The questions in stage 1 of the previous section provide a template for the design of an expert system. For example, the expert system needs to tease out whether the potential user has the appropriate data in a resolution required for model input, and whether the model is being applied in a situation in which it would not be appropriate. A set of "if, then" rules triggers different outputs based on the users' responses (see Starfield and Bleloch 1991 for an in-depth discussion). The expert system generates a decision such as "This model is inappropriate for your needs," or "Use the model cautiously, with the following caveats." A good expert system has explanations attached to the questions and rules that explain the logic behind each step, enabling the potential model user to understand how to answer questions and interpret the expert system's advice.

Expert systems are easy to develop, and a number of expert system shells are freely available on the Internet. Two examples of freeware expert system shells include CLIPS (*www.ghg.net/clips/CLIPS.html*) and e2gLite (*www.expertise2go.com/webesie/*). The major time investment for model developers is to think about how potential users might apply the model and what the users really need to know before they use it. Expert systems are simple to use because of their interactive nature. These systems can be more focused and useful than the information sometimes included in (and often omitted from) a user manual. Expert systems should be embedded in models available for download. Thus, when potential users download a new model, they are presented with the expert system immediately, and spend time considering the suitability of the model for their needs.

What user communities can do

The greater community of ecologists can also become involved in the appropriate sharing of ecological models. For instance, a number of ecological model clearinghouses exist on the Internet where interested ecologists can download and find basic information about free models. Such clearinghouses could be expanded to include expert systems for models; to list key information on a model and contact information for the developers; to provide a forum for discussing difficulties in using the model, interesting applications of the model, and problems in the code; and to encourage ecologists to share their models with colleagues. Some of the existing clearinghouses provide a framework in which this kind of additional information can be added. For instance, the Clearinghouse for Ecology Software (*http://nhsbig.inhs.uiuc.edu/*) run by the Illinois Natural History Survey lists a variety of ecological software dealing with wildlife ecology. For each piece of software, the site lists the authors, version number, revision date, size, operating system requirements, archive format, and a brief description. Such a clearly outlined Web site could be expanded to address some of the items listed above.

A more comprehensive clearinghouse is the Server for Ecological Modelling (*www.wiz.uni-kassel.de/ecobas.html*). This Web site has hundreds of models and describes general and detailed model information, including the main application of the model, citations of publications using the model, and technical information such as programming languages and data requirements. In addition to listing all this pertinent information, such a Web site could be extended to include expert systems and a forum for users to discuss various aspects of the model. Interested members of the user community could contribute expert systems for models when the model developer fails to contribute one. The greater the involvement of the larger community of users, the more likely it is that a model will be used appropriately.

What journal editors can do

Journal editors are in a unique position in that they can hold model developers and model users accountable (i.e., reject a manuscript that involves poor modeling practices). Journal editors should make sure during the process of review that the authors used an appropriate model for their research question and that any new model is thoroughly described in a publication or in a supplemental online document at a site maintained by the publisher (as is already the practice for some journals). Any model that could be used by other ecologists should include a description of the objectives, assumptions, scales, data requirements, output form, and programming language for the model. Any requirements the journal establishes should be explicitly stated in the instructions for authors on the journal Web page.

The obligation to use models appropriately extends beyond individual users, model developers, user communities, and journal editors. For example, college instructors need to explicitly consider the issues raised in this article and discuss them with their students, just as those who make decisions based on model results must raise them with members of their decision analysis teams.

Discussion

Ecologists and conservation biologists are familiar with the use of statistical packages. There is probably an implicit assumption among these scientists that modeling packages can be used in much the same way. This is a poor assumption. Statistics is a discipline with a culture and methodology that modeling still lacks; the literature in statistics constitutes an agreement on model choice and design. When well-intentioned users abuse statistical packages, it is usually because they are ignorant of the assumptions involved. In contrast, well-intentioned users of ecological models will not even be able to find agreement on model design.

Modeling is also an amorphous intellectual exercise. A successful modeling exercise could lead to one or more of the following conclusions: (a) The exercise led the modelers to a different way of stating the problem; (b) it made them think more deeply about the processes and how they interact; (c) it helped generate hypotheses; (d) it helped explain the data better, or helped explain the differences between alternative explanations; (e) it helped create a model that can be used to compare the likely outcomes of alternative management actions; or, rarely, (f) it created a model that can be used to make cautious predictions (e.g., Swartzman 1996, Coughenour and Chen 1997). Perusing this list brings home the realization that designing the model may well be more useful than running it. The process is as important as the product. Any intellectual shortcut, such as using somebody else's model without first going through the process of designing one's own, not only is fraught with hidden pitfalls but represents a lost opportunity for researchers to gain additional insights into the complexities of the systems they are modeling.

One might easily take the position that researchers should *never* use somebody else's model, but there are in fact a number of good reasons for using well-established models. First, using existing code can save considerable time and effort. Even more important, the more the code is used, the more likely it is that programming errors have been eliminated. Ecologists can more efficiently address their questions by making greater use of other people's work, rather than developing a similar or identical model. Also, when using a well-exercised model, one can cite its previous successes, save time on reporting technical details already in the literature, and enporting technical details already in the literature, and enhance the credibility of the study. Others may then have a quicker and more intimate understanding of the model and how it was applied. Users, however, must invest the time to fully understand a model they intend to use. We have presented a structure for doing this.

The ultimate responsibility for model abuse lies with the users, if they have not taken the trouble to tease out the assumptions, objectives, and other important elements of a model. But model developers also have a responsibility. Even in a publication where it is unlikely that somebody else will use a model (table 1, category 3), the author should at least add a paragraph guiding a potential user. For models in categories 1 and 2, developers should be obliged to provide either an expert system or a clearly written exposition on model assumptions and pitfalls to be avoided.

The key to taking advantage of other people's models is to do so within a culture of good practice. We have argued that it is important to initiate a culture and methodology for using other people's models in ecology and conservation biology, and made some suggestions on how to begin the venture. We have described ways in which model users, model developers, journal editors, and the modeling community can facilitate the appropriate sharing of models. It is not hard to see where the culture of good practice could lead. For example, creating expert systems encourages model developers to think about other potential uses and users. Creating the expert system encourages model developers to think beyond their own use to that of other users. Likewise, a culture of previewing a code through an expert system encourages the potential user to think in a structured way about whether and how to use the model; in a sense, it forces the potential user to go through the process of designing a model world. In due course, these practices could become, as they need to become, as important a part of ecological modeling as the models themselves.

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