JASSS
THE JOURNAL OF ARTIFICIAL SOCIETIES AND SOCIAL SIMULATION

Visual ODD: A Standardised Visualisation Illustrating the Narrative of Agent-Based Models

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Journal of Artificial Societies and Social Simulation 27(4) 1, 2024
Doi: 10.18564/jasss.5450 Url: http://jasss.soc.surrey.ac.uk/27/4/1.html

Received: 29-01-2024 Accepted: 03-07-2024 Published: 31-10-2024

Abstract: Agent-based models (ABMs) are commonly used tools across diverse disciplines, from ecology to social sciences and technology. Despite the effectiveness of the widely adopted Overview, Design concepts, and Details (ODD) protocol in ensuring transparency in ABM design and assumptions, the accompanying model descriptions are often lengthy, making quick overviews challenging. To facilitate comprehension, manuscripts, presentations, and posters often include visualisations of the model. Yet, the diversity of visualisation approaches complicates model comparisons and requires additional time for viewers to grasp the figure layouts. Additionally, these visualisations are usually poorly linked to corresponding sections of the written ODD model description. To address these challenges, we propose the standardised visual ODD (vODD) aimed to provide a quick overview of models and simplify the link to the written model description for readers who are more interested in specific elements. The standardised visualisation assigns defined positions for ODD elements for easy reference and comparison. We provide examples and guidance on constructing vODDs, along with templates for modellers to create their own visuals. While advocating for simplicity, we also illustrate how more complex models can still be effectively depicted in such visualisations. By establishing a generalised visualisation applicable to agent-based and other simulation models, we aim to improve the rapid comprehension of models and streamline graphical model representations in manuscripts, presentations, and posters.

Keywords: Individual-Based Model, ODD Protocol, Good Modelling Practice, Conceptual Model Diagram, Graphical Abstract, Science Communication

Introduction

1.1 Reproducibility is the cornerstone of the scientific method. For model-based work, this means that the model used and how it was analysed and applied must be described in such detail that it can be reproduced and the model analysis repeated by others. This should be possible without resorting to the source code that implements the model, as there are simply too many different programming languages. In addition, the reasoning behind key assumptions of the model should be documented. Otherwise it can be difficult to understand why a model behaves in a certain way or how to best interpret its findings.

1.2 While mathematically formulated models can be fully documented using the language of mathematics, simulation models consisting of algorithms do not have such a common language. For agent-based models (ABMs), the ODD protocol has therefore been proposed as a general format for documentation (Grimm et al. 2006, 2010, 2020; Polhill 2010; Polhill et al. 2008). ODD has been widely adopted (Vincenot 2018; Grimm et al. 2020), including applications for model types beyond its original scope. The main feature of ODD is that it starts with an "Overview", which only describes the purpose, entities, state variables, scales, and processes of a model, without going into details. This is followed by a section on "Design concepts", which covers 10 different essential aspects of the design of an agent-based model. Finally, the "Details" section specifies all the technical details for initialising and implementing the model, in addition to the input data that may represent environmental drivers.

1.3 However, ODD has been criticised for its limited capacity to convey the narrative behind the model's design. This is because ODD is not designed to tell a story, but to ensure reproducibility. The ODD model descriptions, despite the "Overview" section, are technical documentations and the level of detail required by ODD was perceived as "sometimes excessive" (Daly et al. 2022). To meet the challenge of providing both a quick overview and technical documentation, Grimm et al. (2020) proposed a common format for a "Summary ODD" but this can still be quite lengthy, especially for more complex ABMs.

1.4 In addition, as ODD was originally developed with ecological systems in mind, models from other research domains are often not documented following the ODD structure, because some elements, particularly in the "Design Concepts" section, may not be fully applicable to them (however, see Müller et al. 2013). Nevertheless, as interdisciplinarity is increasing, facilitating model comparison across domains and improving understanding among modellers from different backgrounds is of growing importance.

1.5 Regardless of the ODD, it has always been a common practice to include a graphical representation of the model to provide a quick overview and understanding of what the model is and does. However, there is no common format for such graphical representations. Consequently, it can require researchers with different backgrounds considerable effort to understand what certain graphical elements should mean (Banitz et al. 2022; Forbes et al. 2023).

1.6 Some well-established, standardised diagrams for simulation models exist. Examples comprise flow and causal-loop diagrams (Richardson 1986). However, such diagrams are often not made for individual-level characteristics and processes or are rather complex to apply (Grimm et al. 2010, 2020). Another standardised graphical representation, primarily used in software development, are Unified Modeling Language (UML) diagrams (Breu et al. 1997). They have been utilised for ABMs, for instance, by Bersini (2012), who applied UML to represent a number of classical ABMs. Yet, similar to flow charts, UML diagrams are characterised by dense text detailing the structure and functioning of submodels. While this level of detail can be very useful in terms of model transferability and transparency, it requires a high familiarity with UML standards for understanding and development. Other visual standardisation efforts are currently rather specific to their domain, for example in areas of ecotoxicological risk assessment (Forbes et al. 2023) or hydrology (Wang et al. 2021).

1.7 We suggest the "visual ODD" (vODD) as a new visually appealing standardised model overview figure applicable across domains. This could make communication of simulation models even more comprehensible and accessible to various stakeholders involved in decision making. Once the use of a new standard visual format has exceeded a certain threshold so that the relevant scientific community recognises it as a familiar and reliable format, it will shape readers' expectations about what kind of visual information they expect where and in what detail. Once this is achieved, the vODD along with the ODD can serve as a checklist for authors, which would eventually make the practice of modelling and model use more coherent and efficient. We also suggest that vODDs could be a useful reference even for modellers not currently using ODDs as they require less detail than ODDs, making them more widely applicable and faster to produce.

1.8 Grimm et al. (2020) briefly mentioned the use of a graphical representation of the ODD, which was originally developed by Milles et al. (2020) and Rohwäder & Jeltsch (2022). However, they did not explain its rationale in detail, nor did they present a set of examples or provide guidance or even tools for creating such vODDs. Nevertheless, it seems that this sample visualisation has already facilitated the acceptance and use of ODD, in particular for beginners in modelling and publishing (D. Parker, personal communication, March 9, 2023).

1.9 Here we aim to elaborate on the initial ideas of visualising ODDs presented in Grimm et al. (2020) by providing guidance on creating vODDs. First, we evaluated the current methods of illustrating simulation models graphically and whether the sample visual ODD, as introduced by Grimm et al. (2020), has been adopted. We reviewed all 248 publications citing the latest ODD update (Grimm et al. 2020) indexed by Web of Science by 15 June 2023 (Appendix D). The majority of publications were associated with life sciences (n = 133), followed by social sciences (n = 60). Among the 248 reviewed publications, 190 featured models, with 171 of them containing ODD documentations. A slightly smaller subset of publications presenting models provided some sort of model visualisation (n = 156, Figure 1A), primarily included in the main text (n = 123). This suggests that most authors already attempt to enhance their models' comprehension by supplementing their written ODDs with visual representations.

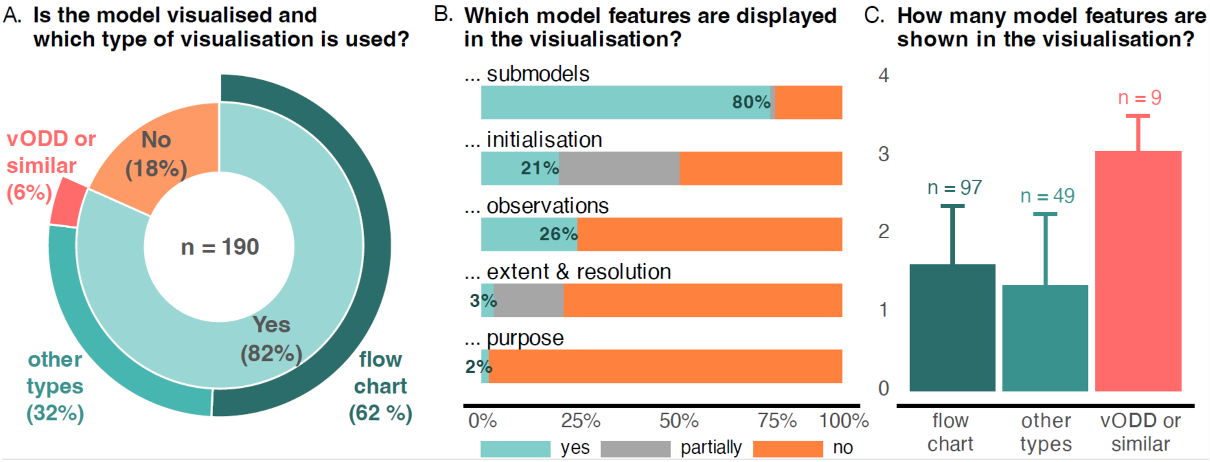

Figure 1: Review of model visualisations from 248 publications citing the latest ODD update by Grimm et al. (2020) (Web of Science, 15 June 2023). A. Most modelling studies include some visualisation for their model, most commonly a flow chart while the vODD structure is not yet widely used. B. 80% of the visualisations include information on the submodels while other modelling features are largely missing, especially scales (extent & resolution) and purpose (n = 190). C. vODDs depict on average twice as many model features as other visualisations. Bars show the mean number of model features included in a visualisation and the standard deviation in each group. The n shows the total number of visualisations in each sub sample.

1.10 However, our review also demonstrates that current model visualisations, in most cases, do not document all the essential model features, including the purpose of the model, information on the initialisation of the simulation, a definition of the spatial/temporal extent and resolution, the primary submodels, and the outputs observed (Figure 1B). Typically, visualisations take the form of flow charts depicting submodels and their order of execution. To a lesser extent, visualisations include initialisation and observations. Only very few visualisations present extents, resolutions, or the model's overarching purpose. On average, flow charts and other visualisation types incorporated fewer than two of these model features. In contrast, vODD comparable visualisations captured an average of three model features providing a stronger link between visualisation and written model documentation (Figure 1C). Interestingly, only nine publications included a visualisation similar to the one provided by Grimm et al. (2020): Milles et al. (2020), Lemanski et al. (2021), Sandhu et al. (2022), Szangolies et al. (2022), Rohwäder & Jeltsch (2022), Byer & Reid (2022), Farthing & Lanzas (2021), Ekanayake-Weber & Swedell (2021), Carturan et al. (2020); assembled in Appendix C.

1.11 While we can see that these "vODD-similar" visualisations can often convey more information about the model and provide a stronger linkage to the written ODD, they are still diverse and have yet to become a common practice. Here we present a straightforward, accessible and uniform scheme for creating vODDs. In the following sections, we outline the scope and content of a vODD, discuss the applicability of vODDs to more complex models, and provide information on available tools.

Definition and Scope of vODD

2.1 To our knowledge, the visual ODD is the first standardised graphical representation for agent-based models universally applicable across multiple research areas. The vODD is a pictorial description of the key elements of the

ODD protocol (Grimm et al. 2006, 2010, 2020), including the initialisation of the model and its entities ("Initialisation"), the scheduling of its processes ("Submodels"), the outputs generated by the model ("Observation"), as well as the spatial/temporal resolution and extent ("Scales"). The purpose is to capture the overall narrative of the model with respect to the full cycle of a simulation. The vODD, like the ODD, is primarily designed to report agent-based models, however, it can be adapted to other dynamic modelling approaches (further explored in the section "Applying vODD to non-agent-based models"). The vODD is designed to be a stand-alone figure that provides a comprehensive overview of an ABM and helps define the scope and purpose of a model. However, modellers seeking to replicate and/or extend an existing model will still need to refer to the detailed description. To this end, each element in the visual ODD has a predefined location and uses the same terminology as the corresponding sections in the written ODD, providing a clear link to where more detailed information can be found. We suggest using vODD to represent ABMs in manuscripts, scientific posters, or talks. The vODD could also serve as a graphical abstract for publications, which is a relatively new trend in scientific journals (Krukowski & Goldstein 2023; Agrawal & Ulrich 2023).

2.2 The establishment of a standardised visualisation for ABMs serves several purposes. The consistency of predefined sections not only helps the viewer locate information of interest easily but also facilitates conceptual comparisons between ABMs. We suggest that the availability of a uniform template and the use of simple open-source tools (see "Tools and tips for creating visual ODDs") could encourage agent-based modellers to document the model overview and its outputs using graphical visualisations. Providing clear and well-designed visual storytelling of the model could enhance the study's accessibility, disseminate the model outputs to a broader audience, including non-modellers, and facilitate interdisciplinary discourse.

2.3 In general, visualisations are an efficient way to provide information quickly and effectively (Oska et al. 2020). While modellers are fully aware of their model's components and dynamics, users of the model might encounter challenges in grasping its structure or even its purpose without the aid of a clear visual representation. Furthermore, we experienced how creating diagrams can help with conceptualising models. For these reasons, best modelling practices recommend the use of diagrams and figures to represent a simulation model and communicate its outputs (Hall & Virrantaus 2016; Forbes et al. 2023). This is consistent with the findings of our review, where over 80% of the reviewed modelling studies included a visual representation of their modelling methods in one or multiple figures (Figure 1A). However, commonly used flow charts often lack features like the initialisation and can become quite large and overwhelming when including details of all submodels. Other scholars depicted selective aspects of the model using multiple diagrams, yet, making it challenging to allow for clear links between them. Alternatively, the vODD builds on the advantages of flow charts, which are commonly used by scholars to describe their models, but formalises them and embeds them with more context. The vODD seeks to provide a visually appealing format with minimal text within a single, cohesive figure.

How to Build a Visual ODD

3.1 Each part of the vODD is linked to one or more sections of the written ODD and has a predefined and fixed position in the figure (see Figure 2). Certain elements of the model description are mandatory and must be included in the vODD. The baseline vODD consists of three main sections, "Initialisation", "Submodels", and "Observations", represented by connected panels, which together represent the full cycle of model structure and simulation.

3.2 The first section, "Initialisation", depicts how a simulation is initialised, including details about entities, their most important state variables, and, if applicable, spatial extents and resolution. The second section, "Submodels", shows the processes and their order of execution, including the temporal resolution (and extent). The final panel, "Observations", presents the information collected from the model. More details on what information to include in each section and where to place it are provided in the following subsections and depicted in Figure 2. Additionally, we provide a vODD template, which can be found in the repository `https://github.com/visual-ODD/Templates.git`, to help constructing your own visualisation. An example of how to apply the template to an existing model is provided in Figure 3, where we rebuild the original suggestion for vODDs by Grimm et al. (2020) visualising the model of Milles et al. (2020). In comparison to Grimm et al. (2020), we added the temporal and spatial scales and made some slight adaptations in presenting the model's entities. Figure 3 further shows some additional panels for the "Purpose" and "Scenario" description, which we propose as optional for vODDs.

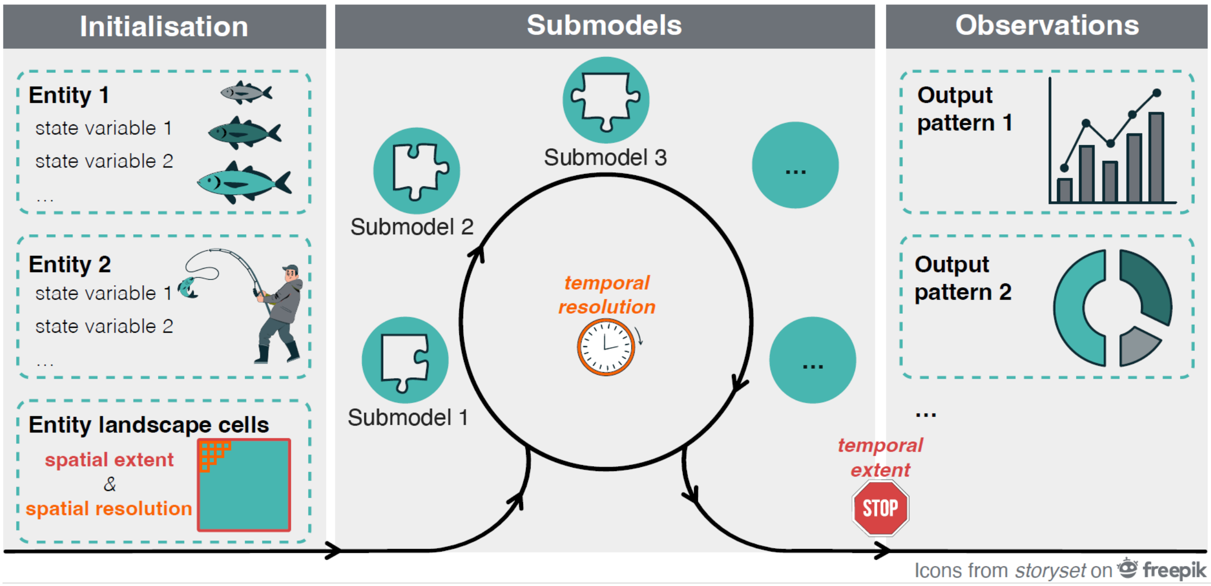

Figure 2: Template representing the standardised layout of the vODD. The icons are exemplary and are not part of the general template. Find template files in the repository `https://github.com/visual-ODD/Templates.git`

3.3 The vODD can be expanded to include optional elements, such as a "Purpose" line, empirical "Patterns" used, or details on "Scenarios" or simulation experiments (see also Appendix A). While these additions can enhance the comprehension of a model study, they also increase the information load and may not always be necessary. As such, we suggest including these elements selectively, particularly when they support the narrative of the study or strengthen the credibility of the model.

3.4 Certain parts of the written ODD have been omitted in the figure for conciseness. For example, details about the "Submodels" are not included. Furthermore, "Design concepts" are not explicitly featured, given their wide variability in applicability across models.

3.5 Although the vODD format can serve as a stand-alone visualisation of a model, it is helpful to be familiar with the written ODD model description format (Grimm et al. 2006, 2010, 2020) to construct it effectively. There are two opposing approaches to building a visual ODD: one can start either by first writing the ODD protocol or by creating the visualisation. Each approach has its own advantages. If the written ODD already exists, the different parts can simply be transferred to the visualisation, such as the entities and the submodel names. In contrast, starting with the visual ODD puts more emphasis on creating clear and concise names for the various components, e.g., submodels, to make them as meaningful and self-explanatory as possible. Furthermore, by using the visualisation as an overview, the visual can guide modellers through the often long and tedious writing process of the written ODD. Additionally, constructing the vODD prior to model implementation may assist in the conceptualisation and implementation process, such as in designing the execution order of model processes or selecting outputs for observation. As model development can be an iterative process, ODD protocol and vODD graphic might also be designed simultaneously.

3.6 As a general guideline, we suggest maintaining clarity in the visualisation by minimising text and choosing icons and colours carefully (more details in the section "Accessibility tips"). The latter also depends heavily on the context in which the figure is to be presented.

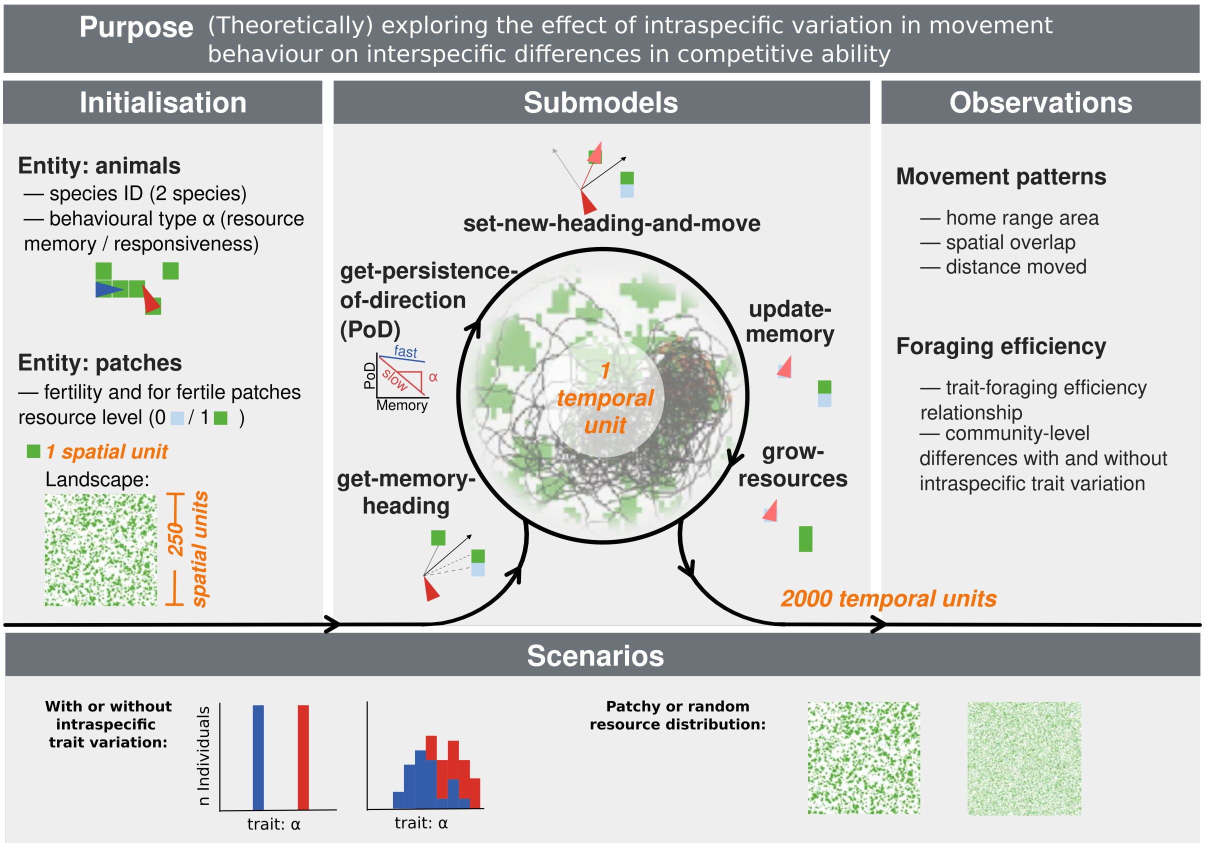

Figure 3: Examplary vODD of the individual-based model presented in Milles et al. (2020). Figure adapted from Milles et al. (2020), Grimm et al. (2020) to match all criteria of the vODD as proposed here. Adaptations include the mentioning of the most important state variables of the entities and the given spatial and temporal scales (in orange). Further, one submodel name was adjusted to be more meaningful and avoid abbreviations (get-persistence-of-direction). Submodel names could be even more self-explanatory, but are here chosen to match the names in the already existing written ODD (Milles et al. 2020). Two optional panels were introduced ("Purpose" and "Scenarios") to clarify model purpose prominently and remove elements describing simulated scenarios from the "Initialisation" panel.

Initialisation

3.7 This element illustrates the setup of the model prior to simulation runs, including details on entities and their key state variables. Agent-based models typically have multiple kinds of entities, in which case we recommend structuring this section by the employed entity types (i.e., individuals, collectives, or spatial units). For spatially-explicit models, the initialisation details of the spatial units, such as grid cells, forming the landscape should be provided, including spatial extents and resolution (see "Scales").

3.8 It is not necessary to include all processes, parameters, or state variables of an entity. The focus should be on providing the relevant information necessary for the viewer to understand how the model operates and the derivation of its final observations. If certain details from the full model description are omitted, this can be indicated in the figure caption, along with a reference directing readers to where the full information can be found, e.g., a table with all state variables in the full ODD in the supplementary material.

3.9 The initialisation may differ among scenarios. However, due to space constraints, this section should provide a generalised setup, while model scenarios or different parameterisations can be optionally presented in a separate panel (see "Optional elements", and example in Figure 3).

Submodels

3.10 This vODD element provides an overview of the model's processes and their order of execution and is therefore closely related to the "Process overview and scheduling" in the ODD. Typically, a simulation model contains several submodels, i.e., algorithms, representing particular processes. Submodels are applied in a defined order or are triggered by certain conditions. We suggest that the names of the submodels are to be placed clockwise around a circle to indicate their repeated scheduling. Submodel names should concisely and clearly describe their purpose and match the names used in the written ODD as closely as possible. Examples may include "Mortality", "Ageing", "Reproduction", "Buying", "Harvesting", "Updating memory", etc. While it is clear that such names may not comprehensively capture the full functioning of the submodels, they provide a quick overview. For in-depth details, viewers can refer to the corresponding section of the written ODD.

3.11 The visualisation along a loop may represent the run once per timestep and / or agent (ABMs) and / or entire model run (non-temporal models). Depending on the number of submodels, font size and placement around the circle can be adapted. If, due to a model's complex dynamics, a single circle is insufficient to present the scheduling of all relevant submodels, multiple circles or alternative visualisations can be used, e.g., to indicate that submodels are run at different temporal resolutions, or that they belong to different entities (see "Visualisation of more complex models" and Figure 4).

3.12 To provide additional context and engage viewers, related icons can be provided next to the names of the submodels. Such icons or pictograms are particularly useful for vODDs intended for posters and presentations, but they may also enhance journal publications when used strategically to provide additional insight into submodel functioning. Icons can be sourced from free platforms or custom-crafted (see "Finding graphics, icons, and fonts").

Observations

3.13 The "Observations" section of the vODD allows the viewer to quickly grasp the main outputs and hence the intended use of the model. This panel could be used to explicitly state the intended purpose, or it may be clear from the reported output variables. Key output patterns of interest directly derived from the model need to be given here, such as time series of population sizes, growth of individuals, income, proportion of conservative land users, etc. When many outputs exist, grouping them can improve readability, for example, grouping by agent types or for population- and individual-level outputs. Including one or two illustrative figures of what such outputs might look like can provide clarity. However, it is important to note that this section aims to highlight only the most important outputs for addressing the model purpose, not to comprehensively cover the entire model analysis.

Scales

3.14 Scales are very important for understanding the scope and dynamics of a model (e.g., McGill et al. 2015), but are often neglected in model visualisations (Figure 1B). To immediately convey the spatial and temporal scales at which a model operates, these elements are mandatory and now have a fixed position in the vODD. This is a new addition compared to the example figure in Grimm et al. (2020) and has been included in the adjusted Figure 3.

3.15 Information about spatial scales is provided in the "Initialisation" section of the vODD, where landscape cells are usually represented as entities. The resolution of individual spatial units and the extent of the entire simulated landscape or environment should be reported for spatial models.

3.16 We positioned temporal dynamics in the "Submodels" section. Our suggestion is to report the duration of a time step (i.e., the temporal resolution) within the loop of submodels. The arrows in the circle indicate that the submodels are repeated for several time steps. If submodels are run with different temporal resolutions, this can be illustrated by using subcycles (see examples in Figure 4). The different time steps may then be written in the center of each loop. Once the simulation is complete, outputs can be analysed. The temporal extent of a simulation run, i.e., the number of simulated time steps or any other stop condition, should, hence, be reported between the "Submodels" and "Observations" sections.

Optional elements

3.17 We suggest several optional sections that can be added to the basic vODD if beneficial for communicating the model and if space permits (see also Appendix A). Firstly, a clear and short statement of the "Purpose" of the model can be given at the top of the figure. Generally, we would highly recommend to state the purpose of the model in all vODDs. In the basic version of the vODD, the purpose can be included within the "Observations" section or in the figure caption, but to make it even more prominent, it can also be placed directly at the top of the figure as in Figure 3. In this case, the purpose should be conveyed as a short and concise statement, avoiding multiple sentences. It could refer to one or more of the general categories of model purposes: prediction, explanation, description, theoretical exploration, illustration, analogy, and social learning (Edmonds et al. 2019).

3.18 In addition, a set of panels for "Patterns" supporting the different phases of model design and evaluation can be included. Such patterns may include data or evidence from relevant literature used for model development or validation, particularly in empirical models. Under the "Initialisation" section, a panel may be used to show patterns relevant to model initialisation, e.g., real landscapes or species distributions. A panel under the "Submodels" section may show patterns from data or literature that are used to define submodel algorithms or their parameters, e.g., mortality rates, movement distributions, home range sizes, etc. A third panel, positioned beneath the "Observations" section, can specifically be used to report patterns used for calibration or validation purposes. To avoid repetition with the "Observations" panel, it should not include results analysis. Including this optional element in a vODD can be useful to increase confidence in a model by showing what information has been incorporated and, in cases, can aid in model comprehension. An example of a vODD including panels for patterns is given in Appendix B (Figure 7). However, due to space limitations, the patterns shown typically represent only a carefully selected subset of the patterns actually used.

3.19 Finally, at the bottom of the figure, an additional panel can be added to illustrate the simulated "Scenarios" (see example in Figure 3). This panel provides space to show alternative scenarios (e.g., landscapes, environmental conditions, income distributions). Varying parameterisations of simulation experiments could be presented graphically or even as a table or short statement of the objective of scenarios (e.g., explore the impact of parameters x & y). Thus, this part of the visualisation does not pertain to the model description itself but rather to the definition of the experiments performed with the model.

Visualisation of More Complex Models

4.1 Models are as diverse as the conceptual approaches of the modellers themselves, making it essential to recognise that not all models may neatly fit into a standard template as presented in section "How to build a vODD". In this section, we provide alternative approaches for applying the vODD framework for these tricky models and offer related examples.

4.2 There are several sources of complexity in agent-based models that may require more detailed vODDs. Examples include comprehensive models that encompass multiple aspects of a single phenomenon (e.g., Preuss et al. 2022), interdisciplinary or hybrid models (Innocenti et al. 2020), multi-scale hierarchical models that operate at various levels of scale (Kruse et al. 2022), models with sequential temporal processes (Kane et al. 2022), and models with multiple-stage decision-making processes yielding a wide range of outcomes (e.g., Reinhard et al. 2022).

4.3 To address the challenge of visualising complex models, we propose breaking them down into simpler structural components and examining their arrangement within the model cycle. Many complex models feature multiple iterative processes, often referred to as "loops," embedded in their dynamic structures. These loops can take various configurations within the model structure. Figure 4 summarises these arrangements in three different classes and some examples are provided in Appendix B. A) Sequential vODDs include multiple loops that run one after the other in a temporal process and have one-way effects. This format may be useful for hierarchical or "nested" ODDs (sensu Grimm et al. 2020) where model documentation presents complex submodels in high detail (example of a hierarchical vODD found in supplementary Figure 6). B) In cases where specific submodels or processes require more emphasis or operate at different temporal resolutions or entities, a vODD composed of two or more loops can be used, with one enclosed within the other, featuring an interactive feedback process (an example is given in supplementary Figure 7). C) Multiple parallel loops that do not substantially interact with each other can be used to represent models with distinct entities or environments. Examples include two adjacent drainage basins or two sport fields hosting games at the same time. We, however, want to emphasise that this list of possible arrangements of cycles may not be exclusive due to the variety and complexity of model implementations. We encourage modellers to be creative and recommend the adaptation of the composition of model cycles dependent on individual model characteristics.

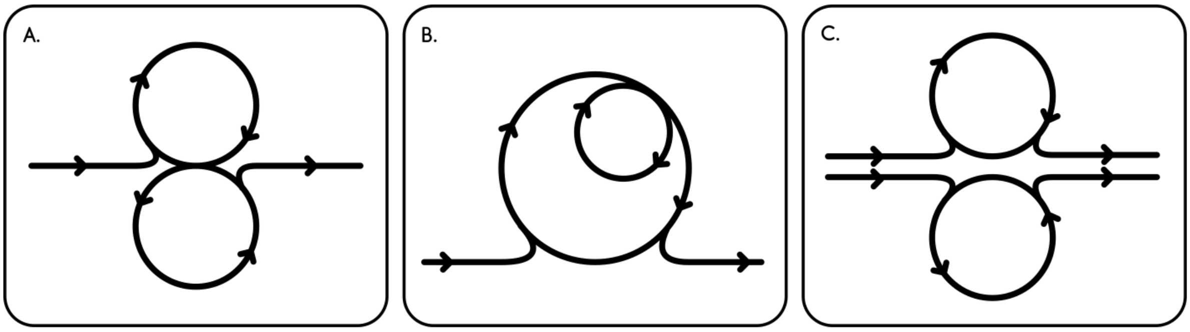

Figure 4: Alternative approaches to representing the process loop for more complex model structures, e.g., submodels with varying temporal resolutions or submodels belonging to different entities: A. Sequential loops organised in a one-way, temporal sequence, suitable for hierarchical or 'nested' model formats; B. Subloops for zooming into specific processes; C. Parallel loops involving multiple non-interactive components.

4.4 Although it is evident that the visualisation of submodels will never capture their full details, one option to cope with a very high degree of complexity, may be digital dynamic vODDs. For example in comprehensive models, where a single phenomenon is represented from multiple interdisciplinary aspects, such digital dynamic vODDs could enhance communication by offering additional details and resolution. These formats may incorporate multimedia, animations, zoom capabilities, or interactive and overlay panels with supplementary information. Guidance on Digital Poster formats may be relevant here, such as provided by interactive presentation tools like *Prezi* (`prezi.com`) or on the *Massachusetts Institute of Technology's Digital Poster guide* (`mitcommlab.mit.edu/nse/commkit/digital-poster`).

Tools and Tips for Creating Visual ODDs

5.1 In the repository `https://github.com/visual-ODD/Templates.git`, we provide a template for creating a vODD available in both a vector graphic format (.svg) and as a *PowerPoint* slide (.pptx). For building your own vODD, you can simply select one of these templates, input the necessary information, and customise it using your preferred software. Alternatively, the layout presented in Figure 2 can be used as a guide to rebuild the vODD structure in completely different software depending on your needs and preferences.

5.2 In this section, we will explore potential graphic design software options for crafting compelling visual ODDs, provide insights on how to source graphics, icons, and typefaces effectively, and emphasise the vital aspects of ensuring accessibility in visual media.

Software options

5.3 When it comes to online graphic design platforms, *Canva* stands out as a popular choice, renowned for its user-friendly interface and an extensive array of templates (`www.canva.com`). However, *Canva's* primary focus is not on scientific content, so adapting its features to suit the specific needs of a vODD might require some effort. Alternatively, *BioRender* offers a specialised option primarily tailored to life sciences, and it can be adapted for other domains (`www.biorender.com`). *BioRender* offers a comprehensive library of icons and templates which may be useful for vODDs. Another viable choice is *Piktochart*, which offers customisable templates for crafting infographics along with a user-friendly interface (`piktochart.com`). *Mind the Graph* is tailored for scientific infographics with a library of icons, templates, and tools to aid in the design process (`mindthegraph.com`). It is important to be aware that while some of these online platforms offer free usage, they may require proper attribution, and others may offer premium content locked behind subscriptions.

5.4 For desktop applications, *Microsoft PowerPoint* may be a familiar option, especially for *Office* users. *PowerPoint*, and similar presentation software, may not be commonly associated with non-presentation formats, but their familiarity and user-friendly nature make them a viable choice, particularly for individuals lacking graphic design experience. *PowerPoint* also provides its own libraries for graphics and icons, which may be useful for vODDs. If a free and open-source graphic design software is preferred, *Inkscape*, a vector graphics editor, offers robust design capabilities, although it may have a steeper learning curve compared to other tools (`inkscape.org`). It provides precise control for crafting intricate visual ODDs and benefits from a supportive community for learning. Finally, *Adobe InDesign*, a paid but professional-grade product, excels in handling complex projects combining text, images, and graphics, making it ideal for visually rich content.

5.5 Ultimately, the selection of specific software will be a personal choice, influenced by user experience level, accessibility, and specific requirements.

Finding graphics, icons, and typefaces

5.6 When creating a visual ODD, the inclusion of icons, symbols, graphics, and non-standard typefaces can significantly enhance the design's clarity and impact (Murchie & Diomede 2020). To find suitable assets, we recommend using relevant keywords in your online searches. For instance, search terms like "icon," "graphics," or "illustration" along with other specific elements required, e.g., a species, process, or concept, can help discover content that aligns with your model's theme. Additionally, consider using reputable online platforms that specialise in providing graphics, icons, and typefaces, such as `Freepik.com`, `Iconfinder.com`, and `fonts.google.com`. These platforms offer an extensive array of both free and premium assets to choose from. Also, some of the software options presented in the previous section offer their own libraries of graphics, icons, and typefaces which are mostly free to use. In cases where these built-in resources align with your needs, they can be a convenient and preferable choice that can help streamline the design process. When incorporating graphics obtained from the internet, proper attribution is required to maintain scientific integrity, i.e., the source and creator's name should be included to give credit where it is due (see example in Figure 2). Authors are expected to adhere to licensing terms specified by the source to avoid copyright issues.

Accessibility tips

5.7 To ensure that your vODD is accessible to a broad audience, consider several key factors. First, when it comes to typefaces and fonts, prioritise legibility by using clear, legible typefaces, and avoiding overly decorative styles (Murchie & Diomede 2020). Sans-serif typefaces are often a better choice as letters can appear less crowded (Russell-Minda et al. 2007), examples include *Arial, Calibri, Verdana, Trebuchet, Comfortaa, Montserrat, Century Gothic, Roboto, Poppins,* and *Noto Sans*. Font size should be at least 12-14 point or equivalent (The British Dyslexia Association 2024). Additionally, resist the temptation to overcrowd your visuals with text; instead, maintain concise wording to enhance comprehension.

5.8 Your colour palette can significantly influence how your vODD is perceived and understood (Murchie & Diomede 2020; Crameri et al. 2020). Choose a palette that is easy on the eyes and provides sufficient contrast between elements. Generally, between three to five colours which complement each other while remaining easy to distinguish should suffice. Colour can and should be used strategically to categorise and group information, set the mood and tone of the piece, navigate the viewer's eye, signal meaning, and create emphasis. Strategic use of colour can enhance communication, engagement, and information conveyance (Murchie & Diomede 2020).

5.9 Furthermore, adhering to colour contrast guidelines, such as those outlined in the "Web Content Accessibility Guidelines" (WCAG) for text and graphics, is essential. These guidelines offer specific contrast levels for different font sizes and scenarios (i.e., AA and AAA compliance). You can reference the WCAG 2.1 guidelines for detailed requirements (`www.w3.org/TR/WCAG21`). To simplify the process, use online colour contrast checkers, such as `www.colourcontrast.cc`, that utilise colour hex codes, as many of these tools incorporate WCAG rules, eliminating the need to memorise specific values. In terms of backgrounds, avoid overly complex patterns or photos, and opt for solid-colour or subtle gradients instead.

5.10 It is crucial to make your visuals friendly to colourblind individuals by ensuring that your colour choices are accommodating. Colourblindness checks can be performed using online colourblindness simulators, like the *Coblis - Color Blindness Simulator*, or built-in functionalities in design software like *Adobe Illustrator*. Additionally, explore colourblind-friendly palettes from sources like *ColorBrewer* (Harrower & Brewer 2003), *Adobe Color Wheel* (`color.adobe.com/create/color-wheel`), or dedicated R packages, such as *RColorBrewer* (Neuwirth 2022) and *viridis* (Garnier et al. 2023). Shapes and labels can additionally be incorporated to convey information effectively, minimising reliance solely on colour cues.

5.11 Finally, ensure appropriate spacing between text and graphics, avoid text justification, and maintain a 1.5 line spacing whenever feasible to prevent overcrowding. Additionally, increasing the inter-character spacing, when possible, can benefit viewers, particularly those with dyslexia (The British Dyslexia Association 2024).

5.12 These comprehensive accessibility tips will help you create a vODD that is inclusive and informative to a diverse audience. More detailed tips can be found in the *Dyslexia Friendly Style Guide* from the British Dyslexia Association (The British Dyslexia Association 2024).

Applying vODD to Non-Agent-Based Models

6.1 The second update of the ODD protocol (Grimm et al. 2020) clarified that only specific elements, primarily encapsulated in the "Design Concepts" section, are unique to ABMs. This distinction has allowed the ODD protocol to be applied to describe non-ABMs, such as matrix models, integral projection models, and ecological-economic models based on difference equations (Grimm et al. 2020).

6.2 In this context, we suggest that vODDs can also be beneficial for non-ABMs which lack inherent visual interpretability. By offering a standard yet flexible framework for representation, a vODD can significantly aid in conveying complex interactions and temporal dynamics often found in these models (Christensen & Walters 2004). Importantly, the framework is adaptable enough to encapsulate the unique characteristics that distinguish non-ABMs from their agent-based counterparts. For example, many non-ABMs, such as system dynamics models or integral projection models, incorporate continuous state variables instead of discrete agents (Ellner & Rees 2006). This nuance could be effectively conveyed through the initialisation in the vODD, making it easier for researchers and stakeholders to understand the model's design and functionality.

6.3 While not all non-ABMs may be suitable for depiction via a vODD, particularly models with iterative elements, or loops, seem fitting for our visual framework. These primarily include process-based models with temporal dynamics or event scheduling (Mangel 2015). Such iterative processes often align with the types of complexity that vODD seeks to clarify.

Summary

7.1 With this work, we aim to establish a standardised format for model visualisations, particularly for ABMs. The presented vODD layout was specifically designed to capture the fundamental concepts of a model and provide an overview of the full simulation cycle. The provided user-friendly template, along with practical tools and tips, facilitates the creation of such visualisations for each individual model. With our standardised visualisation format we hope to simplify model communication and comparison, and increase model understanding and acceptance among modellers and non-modellers alike. Further, we anticipate that standardised visuals will encourage the reuse of models by establishing a clear link between an attention-grabbing model visualisation and the detailed model description, in the form of a written ODD, needed for reimplementation. Hence, vODDs can serve as an initial, accessible and concise overview of models, suitable for inclusion in manuscripts, presentations, and posters.

Acknowledgements

This study was conducted within the DFG funded research training group 'BioMove' (DFG-GRK 2118/2). We thank the CIHR / SSHRC / NSERC SMART training platform and The Waterloo Institute for Complexity and Innovation. We would like to thank Dawn Parker who reported on the success of a visual ODD in improving the accessibility of ODD in student courses. We also want to thank the editor of JASSS and two anonymous reviewers.

Appendix A: vODD with Optional Elements

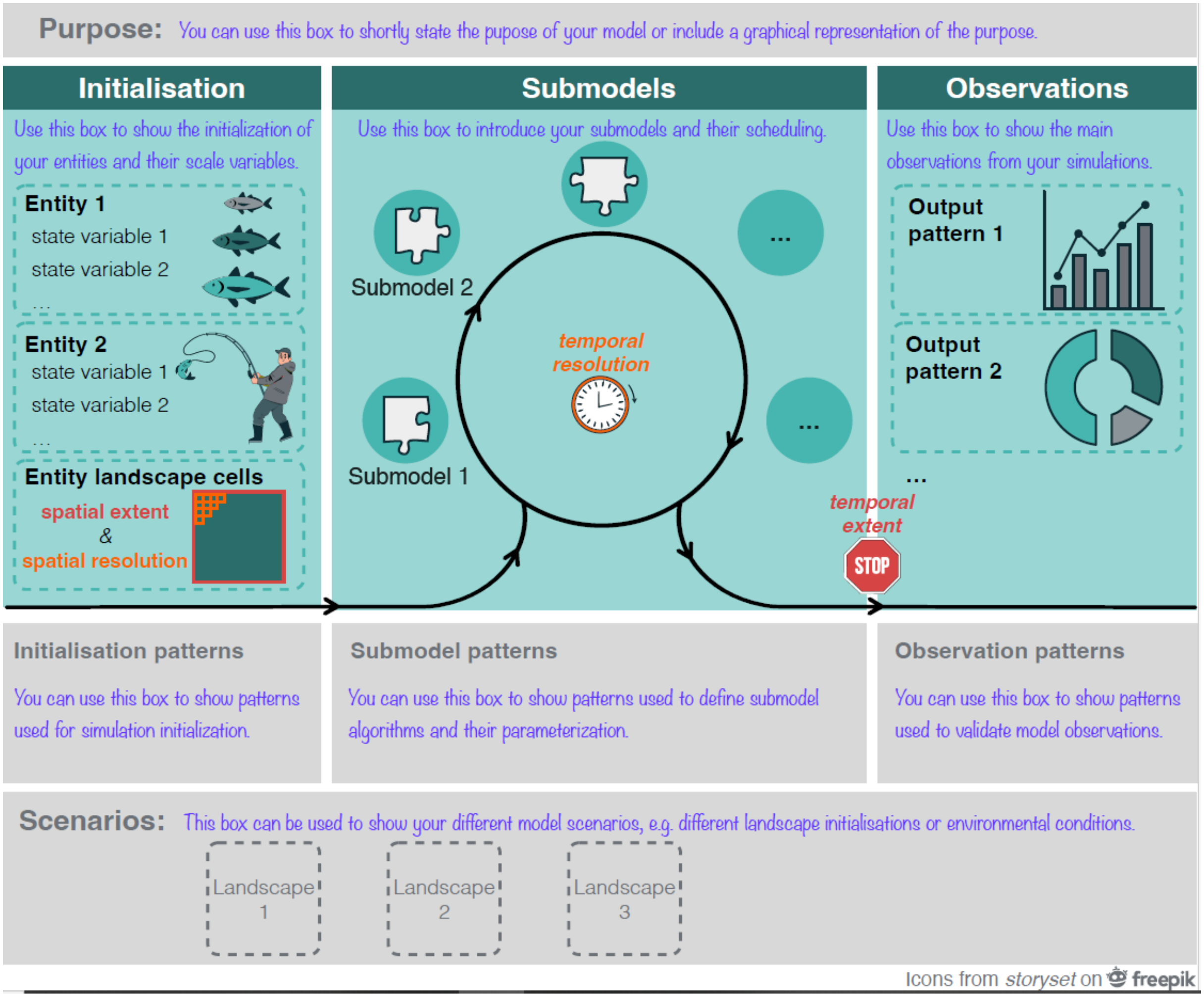

Figure 5: Template representing the standardised layout of the vODD including the position of optional elements and short explanations of which info to present in each box. Find the templates in the repository `https://github.com/visual-ODD/Templates.git`

Appendix B: Examples for More Complex Models (Compare to Figure 4)

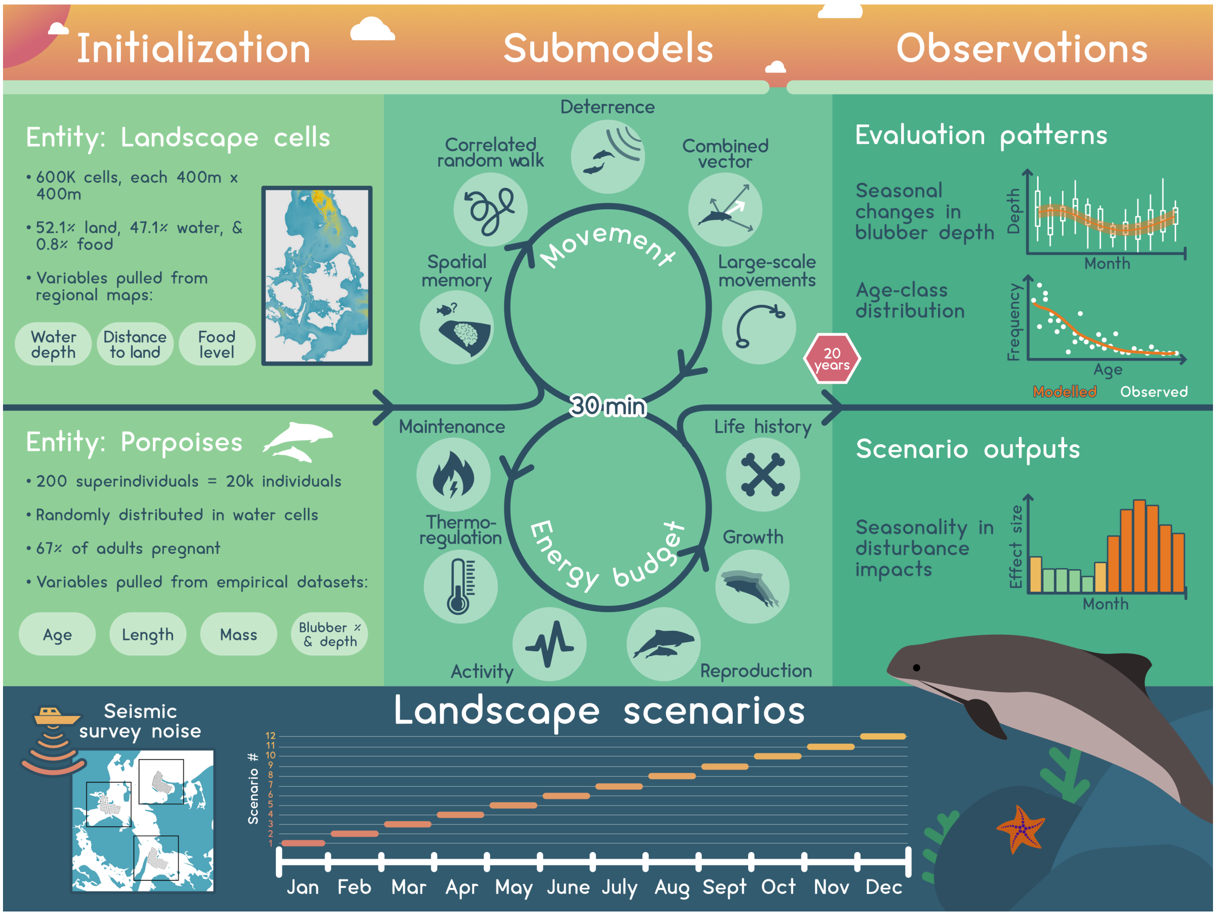

Figure 6: Example hierarchical vODD from Gallagher et al. 2021, illustrating detailed representations of two critical submodels—animal movement and energy budgets—through the use of sequential process loops.

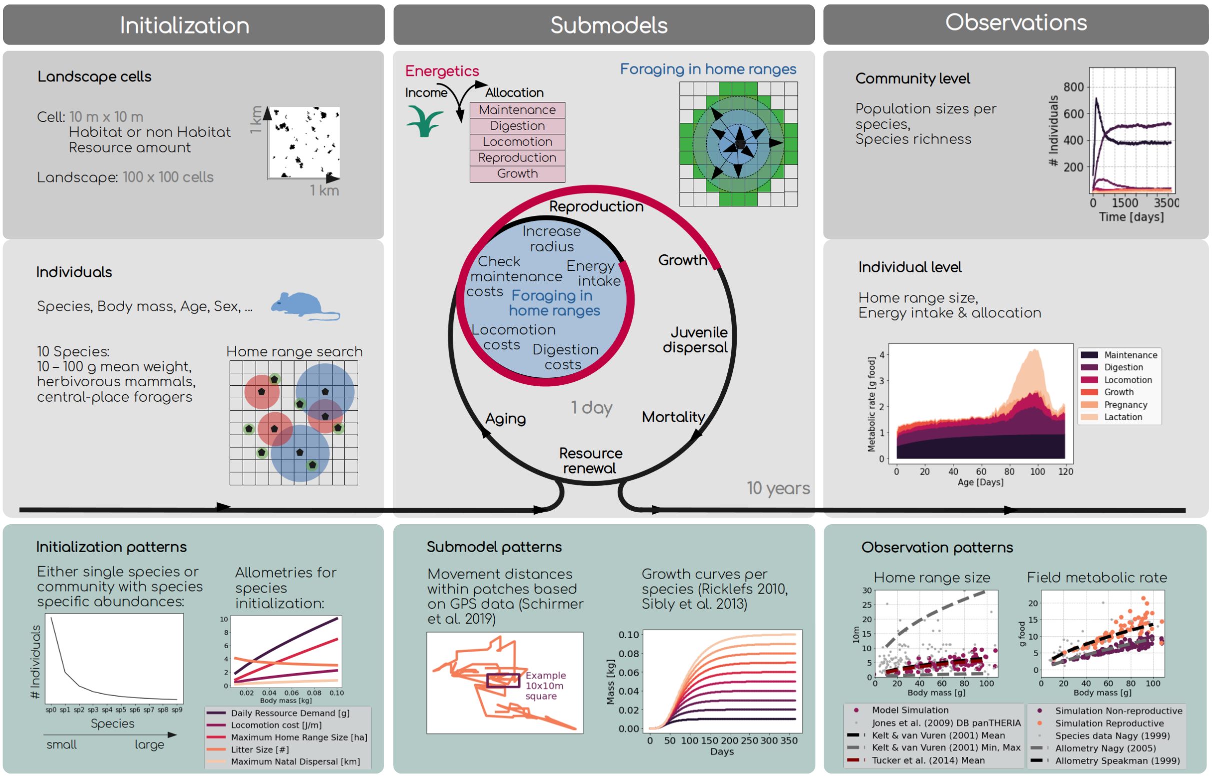

Figure 7: Example nested vODD from Szangolies et al. (in press; Journal of Animal Ecology), visualising a home range search submodel loop within the general daily timestep loop of each individual. Additionally, the energy budget submodel is represented using the colour red, illustrating another possibility how to show complex submodels. As proposed in the optional elements of a vODD a row of patterns is included below the core vODD. These are exemplary patterns used for model initialisation, submodel definition, and output validation.

Appendix C: Visualisations Classified as "vODD or Similar"

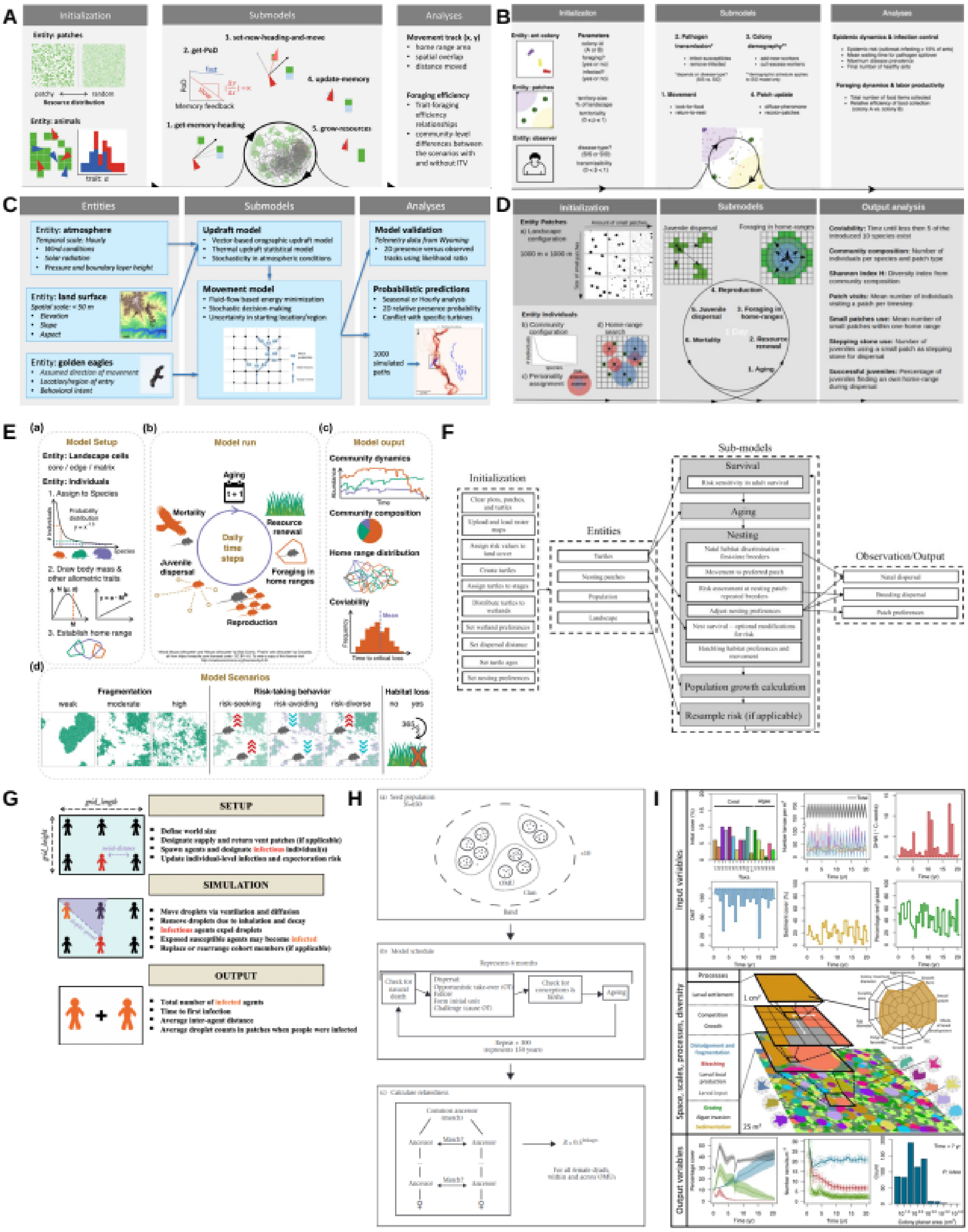

Figure 8: The 9 figures that were classified as "vODD or similar" in the review of 248 publications citing the latest ODD update by Grimm et al. (2020) (Web of Science, 15 June 2023). All figures clearly include the three sections Initialisation / Setup, Submodels / Simulation, and Output / Observation. Various formats of the vODD emerged since Grimm et al. (2020) did not provide a description of their vODD example. I.e., A - F provide the sections horizontally and G - I show them vertically. Some figures include a circle for submodels (A, B, D, E, H), others do not. Figures A, B, D, and E most clearly resemble our proposed vODD. A: Milles et al. (2020); B: Lemanski et al. (2021), C: Sandhu et al. (2022); D: Szangolies et al. (2022); E: Rohwäder & Jeltsch (2022); F: Byer & Reid (2022); G: Farthing & Lanzas (2021); H: Ekanayake-Weber & Swedell (2021); I: Carturan et al. (2020).

Appendix D: Review Table

Table 1: Review table of the 248 publications citing the latest ODD update by Grimm et al. (2020) indexed by Web of Science by 15 June 2023

ID	model	visualisation	initialisation	scales & resolution	purpose	sub-models	output variables	placement	ODD	temporal model	spatial model	discipline
1	yes	none							yes	yes	no	life science
2	no											life science
3	no											social science
4	yes	flow chart	partially	partially	no	yes	no	manuscript	yes	yes	yes	life science
5	yes	other	partially	no	no	no	no	manuscript	yes	yes	yes	life science
6	no											life science
7	no											social science
8	no											physical science
9	no											life science
10	no											life science
11	yes	flow chart	no	no	no	yes	no	manuscript	yes	no	yes	life science
12	no											life science
13	yes	other	no	no	no	no	no	manuscript	yes	yes	no	life science
14	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	yes	life science
15	yes	none							yes	yes	yes	life science
16	no											life science
17	no											life science
18	no											life science
19	yes	flow chart	no	no	no	yes	no	appendix	yes	yes	yes	life science
20	yes	other	partially	partially	no	no	no	manuscript	no	yes	no	life science
21	yes	none							yes	yes	yes	life science
22	no											physical science
23	yes	flow chart	no	no	no	yes	no	manuscript	yes	no	no	social science
24	yes	other	no	partially	no	yes	no	manuscript	yes	yes	yes	life science
25	yes	flow chart	partially	partially	yes	yes	yes	appendix, manuscript	yes	yes	yes	life science
26	no											life science
27	yes	flow chart	partially	no	no	yes	no	manuscript	yes	yes	yes	life science
28	yes	other	yes	partially	no	no	no	appendix	yes	yes	no	life science
29	yes	other	no	no	no	yes	no	manuscript	yes	yes	no	life science
30	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	yes	life science
31	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	no	life science
32	yes	none							yes	yes	yes	life science
33	yes	vodd	yes	no	no	yes	yes	manuscript	yes	yes	yes	life science
34	yes	flow chart	no	no	yes	yes	no	manuscript	yes	yes	no	social science
35	yes	vodd	no	partially	no	yes	yes	manuscript	yes	yes	yes	life science
36	yes	flow chart	no	no	no	yes	no	appendix	yes	yes	no	social science
37	yes	other	partially	no	no	no	no	appendix	yes	yes	yes	social science
38	yes	flow chart	partially	no	no	yes	no	appendix	yes	yes	yes	life science
39	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	yes	life science
40	yes	flow chart	partially	no	no	yes	no	manuscript	yes	yes	yes	life science
41	yes	other	no	no	no	yes	yes	manuscript	yes	yes	yes	life science
42	yes	none							yes	yes	yes	social science
43	no											social science
44	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	yes	life science
45	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	yes	life science
46	yes	other	no	no	no	yes	no	manuscript	yes	yes	yes	social science
47	no											
48	yes	none	no	no	no	no	no		no	yes	no	social science
49	yes	other	yes	no	no	no	no	manuscript	no	no	no	social science
50	no											
51	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	yes	life science
52	yes	other	no	no	no	no	no	manuscript	yes	yes	yes	life science
53	no											
54	yes	none							yes	yes	yes	life science
55	no											
56	no											
57	yes	flow chart	yes	no	no	yes	no	manuscript	yes	yes	yes	life science
58	yes	flow chart	partially	no	no	yes	no	manuscript	yes	yes	yes	social science
59	yes	other	yes	no	no	yes	yes	manuscript	yes	yes	yes	life science
60	yes	none							yes	yes	yes	life science
61	no											
62	yes	flow chart	no	no	no	yes	no	manuscript	yes	no	yes	life science
63	yes	other	no	no	no	yes	no	manuscript	yes	yes	no	life science
64	no											
65	yes	vodd	yes	yes	no	yes	yes	manuscript	yes	yes	no	life science
66	yes	other	yes	no	no	yes	yes	manuscript	yes	yes	yes	life science
67	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	no	life science
68	yes	none							no	yes	yes	life science
69	yes	flow chart	partially	no	no	yes	no	manuscript	yes	yes	yes	life science
70	yes	flow chart	yes	no	no	yes	yes	manuscript	yes	yes	yes	social science

71	no											life science
72	yes	vodd	yes	no	no	yes	yes	appendix	yes	yes	yes	life science
73	yes	other	partially	partially	no	no	no	manuscript	yes	yes	yes	life science
74	no											
75	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	no	social science
76	yes	flow chart	yes	no	no	yes	no	manuscript	no	yes	no	social science
77	yes	other	yes	no	no	yes	yes	manuscript	yes	yes	no	life science
78	yes	flow chart	yes	no	no	yes	no	appendix	yes	yes	yes	life science
79	yes	flow chart	yes	no	no	yes	no	appendix	yes	yes	yes	life science
80	yes	none							yes	yes	yes	life science
81	yes	flow chart	yes	no	no	yes	no	manuscript	yes	yes	yes	life science
82	yes	flow chart	no	no	no	yes	yes	manuscript	yes	yes	no	social science
83	yes	flow chart	no	no	no	yes	yes	appendix	yes	yes	no	social science
84	yes	other	partially	no	no	yes	no	manuscript	yes	yes	no	social science
85	yes	flow chart	partially	no	no	yes	yes	manuscript	yes	yes	yes	life science
86	no											
87	no											
88	yes	other	partially	no	no	yes	no	manuscript	yes	yes	yes	social science
89	yes	other	yes	no	no	yes	no	manuscript	yes	yes	yes	physical science
90	no											
91	yes	other	partially	no	no	yes	no	manuscript	yes	yes	no	life science
92	yes	flow chart	partially	no	no	no	no	manuscript	yes	yes	yes	life science
93	yes	other	partially	no	no	yes	no	manuscript	yes	yes	yes	social science
94	yes	other	partially	no	no	no	no	manuscript	yes	yes	yes	physical science
95	yes	other	partially	no	no	no	yes	manuscript	yes	yes	yes	life science
96	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	no	life science
97	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	yes	life science
98	yes	flow chart	yes	no	no	yes	no	manuscript	yes	yes	no	social science
99	yes	flow chart	yes	no	no	yes	no	appendix	yes	yes	no	life science
100	yes	other	yes	yes	no	no	no	manuscript	yes	yes	yes	physical science
101	yes	other	yes	yes	no	no	no	manuscript	yes	yes	yes	life science
102	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	no	life science
103	yes	other	partially	no	no	no	no	manuscript	no	yes	yes	physical science
104	no											
105	yes	other	no	no	no	yes	yes	manuscript	no	yes	yes	physical science
106	no											life science
107	no											social science
108	no											physical science
109	yes	other	partially	partially	no	no	yes	manuscript	yes	no	yes	social science
110	yes	none							yes	yes	yes	social science
111	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	no	health science
112	yes	none							yes	yes	yes	life science
113	yes	other	no	no	no	yes	no	manuscript	yes	yes	yes	life science
114	article re-tracted!											
115	yes	other	no	no	no	no	no	manuscript	no	no	no	life science
116	yes	flow chart	partially	partially	no	yes	no	manuscript	yes	yes	yes	social science
117	yes	flow chart	no	no	no	yes	no	manuscript	no	yes	no	social science
118	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	yes	life science
119	yes	none							no	yes	no	social science
120	yes	none							yes	yes	no	life science
121	yes	other	no	no	no	no	no	manuscript	no	yes	no	life science
122	yes	flow chart	no	no	no	yes	yes	manuscript	yes	yes	yes	life science
123	yes	other	partially	partially	no	yes	yes	manuscript	no	no	yes	physical science
124	yes	other	partially	no	no	yes	yes	manuscript	yes	yes	yes	life science
125	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	no	physical science
126	no											life science
127	yes	flow chart	partially	partially	no	yes	yes	manuscript	yes	yes	yes	physical science
128	yes	flow chart	partially	partially	no	yes	yes	manuscript	yes (odd+d)	yes	yes	social science
129	yes	flow chart	partially	no	no	yes	yes	manuscript	yes	yes	yes	life science
130	yes	flow chart	yes	partially	no	yes	no	manuscript	yes	yes	yes	life science
131	yes	vodd	yes	no	no	yes	yes	manuscript	yes	yes	yes	life science
132	yes	other	no	no	no	no	no	manuscript	yes	yes	yes	life science
133	yes	flow chart	yes	partially	no	yes	no	manuscript	yes	yes	yes	health science
134	yes	flow chart	partially	partially	no	no	yes	manuscript	yes	yes	yes	health science
135	yes	flow chart	partially	partially	no	yes	yes	manuscript	yes	yes	yes	life science
136	no								yes			social science
137	yes	flow chart	yes	no	no	yes	no	manuscript	yes	yes	yes	life science
138	yes	flow chart	no	no	no	yes	yes	manuscript	yes	ues	yes	life science
139	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	yes	life science
140	yes	none							no	yes	yes	social science
141	no											
142	yes	none							yes	yes	yes	life science
143	yes	flow chart	no	no	no	no	no	manuscript	yes	yes	yes	life science
144	yes	other	partially	partially	no	yes	yes	manuscript	yes	yes	no	health science
145	yes	flow chart	partially	no	no	yes	yes	appendix	yes	yes	yes	health science
146	yes	none							yes	yes	yes	health science
147	yes	flow chart	yes	no	no	yes	yes	manuscript & supp.	yes	yes	yes	life science
148	yes	vodd	yes	partially	no	yes	yes	manucsript	yes	yes	yes	life science

149	yes	other	partially	partially	no	yes	yes	manuscript	yes	yes	yes	life science
150	yes	flow chart	partially	no	no	yes	yes	manunscript	yes	yes	yes	social science
151	yes	flow chart	partially	no	no	yes	yes	manuscript	yes	yes	no	physical science
152	yes	none							yes	yes	yes	life science
153	no								no			life science
154	yes	flow chart	yes	partially	no	yes	no	manuscript	yes	yes	yes	social science
155	no								yes			social science
156	yes	none							yes	yes	yes	life science
157	yes	other	yes	yes	no	no	yes	appendix	yes	yes	yes	health science
158	yes	flow chart	no	partially	no	yes	no	manuscript	yes	yes	yes	social science
159	yes	other						manuscript	yes	yes	yes	life science
160	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	yes	life science
161	no											social science
162	yes	flow chart	partially	no	no	yes	no	manuscript	yes	yes	yes	social science
163	yes	flow chart	partially	no	no	yes	no	manuscript	yes	yes	yes	life science
164	yes	flow chart	partially	no	yes	yes	no	manuscript	yes	yes	yes	life science
165	no	none							no	no	no	
166	yes	flow chart	yes	partially	no	yes	yes	manuscript	yes	yes	yes	social science
167	yes	flow chart	partially	no	no	yes	no	manuscript	yes	yes	yes	life science
168	yes	flow chart	partially	no	no	yes	no	manuscript	no	yes	yes	health science, social science
169	yes	flow chart	partially	no	no	yes	no	appendix	yes	yes	yes	life science
170	yes	other	partially	partially	no	no	no	manuscript	yes	yes	yes	life science
171	yes	none							yes	yes	yes	life science
172	yes	flow chart	no	no	no	yes	yes	manuscript	yes	yes	yes	life science
173	yes	flow chart	partially	no	no	yes	no	manuscript	yes	yes	yes	life science
174	yes	flow chart	partially	no	no	yes	no	manuscript	yes	yes	yes	life science
175	yes	flow chart	yes	partially	no	yes	no	manuscript, appendix	yes	yes	yes	life science
176	yes	none							yes	yes	yes	life science, social science
177	no											
178	no											
179	yes	none							yes	yes	no	life science
180	no											
181	yes	none							yes	yes	yes	social science
182	no											
183	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	yes	life science
184	no											
185	yes	none							yes	yes	yes	life science
186	yes	flow chart	no	no	no	yes	no	appendix	yes	yes	yes	life science
187	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	yes	social science
188	yes	none							yes	yes	yes	life science
189	yes	vodd	yes	no	no	yes	yes	manuscript	yes	yes	yes	life science
190	no											
191	yes	other	no	no	no	no	no	manuscript	yes	yes	yes	life science
192	yes	vodd	partially	partially	no	yes	yes	manuscript	yes	yes	yes	life science
193	yes	flow chart	no	no	no	yes	no	appendix	yes	yes	yes	social science
194	yes	none							yes	yes	yes	life science
195	yes	flow chart	no	no	no	yes	no	appendix	yes	yes	yes	life science
196	yes	flow chart	partially	partially	no	yes	yes	manuscript	yes	yes	yes	life science
197	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	yes	life science
198	yes	other	no	no	no	partially	no	manuscript	yes	yes	no	social science
199	yes	flow chart	partially	no	no	yes	no	manuscript	yes	yes	yes	social science, health science
200	no											
201	yes	other	no	no	no	yes	no	manuscript	partially	yes	no	social science
202	yes	none							partially	yes	yes	life science
203	yes	flow chart	no	no	no	partially	no	manuscript	yes	yes	yes	life science
204	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	no	life science
205	no											
206	no											
207	no											
208	yes	vodd	yes	partially	no	no	yes	manuscript	yes	yes	yes	life science
209	no											life science
210	yes	other	no	no	no	yes	no	manuscript	yes	yes	yes	social science
211	yes	flow chart	yes	yes	no	yes	no	manuscript	yes	yes	no	life science
212	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	yes	life science
213	yes	other	no	no	no	yes	no	manuscript	yes	yes	yes	life science
214	yes	none							yes	yes	no	social science
215	yes	none							no	yes	yes	health science
216	yes	other	partially	no	no	yes	no	manuscript	yes	yes	yes	life science
217	no											
218	no											
219	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	unclear	social science
220	no											health science
221	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	yes	life science
222	yes	other	partially	no	no	yes	no	manuscript	yes	yes	yes	social science
223	yes	other	no	partially	no	no	no	manuscript	yes	yes	no	life science
224	yes	other	yes	no	no	no	no	manuscript	no	yes	yes	health science
225	no											
226	yes	flow chart	no	no	no	no	no	manuscript	no	yes	yes	social science

227	no											
228	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	no	social science
229	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	yes	life science
230	no											
231	yes	none							no	yes	yes	life science
232	yes	other	no	no	no	yes	no	manuscript	yes	yes	no	social science
233	yes	flow chart	partially	no	no	yes	no	manuscript	yes	yes	yes	social science
234	yes	flow chart	partially	no	no	yes	no	manuscript	no	yes	no	life science
235	yes	flow chart	partially	partially	no	yes	no	manuscript	yes	yes	yes	life science
236	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	yes	life science
237	yes	flow chart	no	partially	no	no	yes	manuscript	yes	yes	yes	social science
238	no								yes			social science
239	no								yes			
240	yes	none							yes	yes	yes	health science
241	no											
242	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	yes	social science
243	yes	other	partially	no	no	no	no	manuscript	yes	yes	yes	social science
244	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	no	life science
245	yes	none							yes	yes	yes	life science
246	yes	none							no	yes	yes	social science
247	yes	none							yes	yes	yes	social science
248	yes	flow chart	no	no	no	yes	no	manuscript	yes	yes	yes	social science

Table 2: Article belonging to the identifier

ID	Authors	Title	Year
1	Accolla, C; Forbes, VE	Temperature dependence of population responses to competition and metabolic stress: An agent-based model to inform ecological risk assessment in a changing climate	2021
2	Accolla, C; Vaugeois, M; Grimm, V; Moore, AP; Rueda-Cediel, P; Schmolke, A; Forbes, VE	A Review of Key Features and Their Implementation in Unstructured, Structured, and Agent-Based Population Models for Ecological Risk Assessment	2021
3	Achter, S; Borit, M; Chattoe-Brown, E; Siebers, PO	RAT-RS: a reporting standard for improving the documentation of data use in agent-based modelling	2022
4	Agudelo, MS; Grant, WE; Wang, HH	Effects of white-tailed deer habitat use preferences on southern cattle fever tick eradication: simulating impact on pasture vacation strategies	2021
5	Ahmad, RA; Imron, MA; Ramadona, AL; Lathifah, N; Azzahra, F; Widyastuti, K; Fuad, A	Modeling social interaction and metapopulation mobility of the COVID-19 pandemic in main cities of highly populated Java Island, Indonesia: An agent-based modeling approach	2023
6	Akhatova, A; Kranzl, L; Schipfer, F; Heendeniya, CB	Agent-Based Modelling of Urban District Energy System Decarbonisation-A Systematic Literature Review	2022
7	Alegria, MEO; Schutze, N; Zipper, SC	A Serious Board Game to Analyze Socio-Ecological Dynamics towards Collaboration in Agriculture	2020
8	Alvarez, E; Brida, JG; London, S	ABM DOCUMENTATION AND ODD PROTOCOL IN ECONOMICS: A BIBLIOMETRIC ANALYSIS	2021
9	An, L; Grimm, V; Sullivan, A; Turner, BL; Malleson, N; Heppenstall, A; Vincenot, C; Robinson, D; Ye, XY; Liu, JG; Lindkvist, E; Tang, WW	Challenges, tasks, and opportunities in modeling agent-based complex systems	2021
10	Anshuka, A; van Ogtrop, FF; Sanderson, D; Leao, SZ	A systematic review of agent-based model for flood risk management and assessment using the ODD protocol	2022
11	Arraut, EM; Walls, SW; Macdonald, DW; Kenward, RE	Anticipation of common buzzard population patterns in the changing UK landscape	2021
12	Ayllon, D; Railsback, SF; Gallagher, C; Augusiak, J; Baveco, H; Berger, U; Charles, S; Martin, R; Focks, A; Galic, N; Liu, C; van Loon, EE; Nabe-Nielsen, J; Piou, C; Polhill, JG; Preuss, TG; Radchuk, V; Schmolke, A; Stadnicka-Michalak, J; Thorbek, P; Grimm, V	Keeping modelling notebooks with TRACE: Good for you and good for environmental research and management support	2021
13	Bahlburg, D; Meyer, B; Berger, U	The impact of seasonal regulation of metabolism on the life history of Antarctic krill	2021
14	Baltiansky, L; Frankel, G; Feinerman, O	Emergent regulation of ant foraging frequency through a computationally inexpensive forager movement rule	2023
15	Bampoh, DK; Earl, JE; Zollner, PA	Simulating the relative effects of movement and sociality on the distribution of animal-transported subsidies	2021
16	Banitz, T; Hertz, T; Johansson, LG; Lindkvist, E; Martinez-Pena, R; Radosavljevic, S; Schluter, M; Wennberg, K; Ylikoski, P; Grimm, V	Visualization of causation in social-ecological systems	2022
17	Banitz, T; Schluter, M; Lindkvist, E; Radosavljevic, S; Johansson, LG; Ylikoski, P; Martinez-Pena, R; Grimm, V	Model-derived causal explanations are inherently constrained by hidden assumptions and context: The example of Baltic cod dynamics	2022
18	Bartkowski, B; Schussler, C; Muller, B	Typologies of European farmers: approaches, methods and research gaps	2022
19	Bathmann, J; Peters, R; Reef, R; Berger, U; Walther, M; Lovelock, CE	Modelling mangrove forest structure and species composition over tidal inundation gradients: The feedback between plant water use and porewater salinity in an arid mangrove ecosystem	2021
20	Bayram, A; Marvuglia, A; Myridinas, M; Porcel, M	Increasing Biowaste and Manure in Biogas Feedstock Composition in Luxembourg: Insights from an Agent-Based Model	2023
21	Beckford, C; Ferita, M; Fucarino, J; Elzinga, DC; Bassett, K; Carlson, AL; Swanson, R; Capaldi, A	Pollen interference emerges as a property from agent-based modelling of pollen competition in Arabidopsis thaliana	2022
22	Bellomo, N; Knopoff, DA; Terna, P	Special Issue Kinetic Theory and Swarming Tools to Modeling Complex Systems-Symmetry problems in the Science of Living Systems-Editorial and Research Perspectives	2020
23	Bellora-Bienengraber, L; Harten, C; Meyer, M	The effectiveness of risk assessments in risk workshops: the role of calculative cultures	2023
24	Berre, D; Diarisso, T; Andrieu, N; Le Page, C; Corbeels, M	Biomass flows in an agro-pastoral village in West-Africa: Who benefits from crop residue mulching?	2021
25	Bogdanowski, A; Banitz, T; Muhsal, LK; Kost, C; Frank, K	McComedy: A user-friendly tool for nextgeneration individual-based modeling of microbial consumer-resource systems	2022
26	Boyd, J; Wilson, R; Elsenbroich, C; Heppenstall, A; Meier, P	Agent-Based Modelling of Health Inequalities following the Complexity Turn in Public Health: A Systematic Review	2022

27	Boyd, R; Walker, N; Hyder, K; Thorpe, R; Roy, S; Sibly, R	SEASIM-NEAM: A Spatially-Explicit Agent-based SIMulator of North East Atlantic Mackerel population dynamics	2020
28	Brock, J; Lange, M; Guelbenzu-Gonzalo, M; Meunier, N; Vaz, AM; Tratalos, JA; Dittrich, P; Gunn, M; More, SJ; Graham, D; Thulke, HH	Epidemiology of age-dependent prevalence of Bovine Herpes Virus Type 1 (BoHV-1) in dairy herds with and without vaccination	2020
29	Brock, J; Lange, M; Tratalos, JA; More, SJ; Guelbenzu-Gonzalo, M; Graham, DA; Thulke, HH	A large-scale epidemiological model of BoHV-1 spread in the Irish cattle population to support decision-making in conformity with the European Animal Health Law	2021
30	Brosnan, IG; Welch, DW	A model to illustrate the potential pairing of animal biotelemetry with individual-based modeling	2020
31	Buckley, C; Field, M; Vu, TM; Brennan, A; Greenfield, TK; Meier, PS; Nielsen, A; Probst, C; Shuper, PA; Purshouse, RC	An integrated dual process simulation model of alcohol use behaviours in individuals, with application to US population-level consumption, 1984-2012	2022
32	Butts, DJ; Thompson, NE; Christensen, SA; Williams, DM; Murillo, MS	Data-driven agent-based model building for animal movement through Exploratory Data Analysis	2022
33	Byer, NW; Reid, BN	The emergence of imperfect philopatry and fidelity in spatially and temporally heterogeneous environments	2022
34	Cao, S; MacLaren, NG; Cao, YD; Marshall, J; Dong, YJ; Yammarino, FJ; Dionne, SD; Mumford, MD; Connelly, S; Martin, RW; Standish, CJ; Newbold, TR; England, S; Sayama, H; Ruark, GA	Group Size and Group Performance in Small Collaborative Team Settings: An Agent-Based Simulation Model of Collaborative Decision-Making Dynamics	2022
35	Carturan, BS; Pither, J; Marechal, JP; Bradshaw, CJA; Parrott, L	Combining agent-based, trait-based and demographic approaches to model coral-community dynamics	2020
36	Castanon-Puga, M; Rosales-Cisneros, RF; Acosta-Prado, JC; Tirado-Ramos, A; Khatchikian, C; Aburto-Camacllanqui, E	Earned Value Management Agent-Based Simulation Model	2023
37	Chapuis, K; Pham, MD; Brugiere, A; Zucker, JD; Drogoul, A; Tranouez, P; Daude, E; Taillandier, P	Exploring multi-modal evacuation strategies for a landlocked population using large-scale agent-based simulations	2022
38	Chen, SH; Londono-Larrea, P; McGough, AS; Bible, AN; Gunaratne, C; Araujo-Granda, PA; Morrell-Falvey, JL; Bhowmik, D; Fuentes-Cabrera, M	Application of Machine Learning Techniques to an Agent-Based Model of Pantoea	2021
39	Chen, YF; Xu, LY; Zhang, X; Wang, ZL; Li, HL; Yang, YS; You, H; Li, DH	Socio-econ-ecosystem multipurpose simulator (SEEMS): An easy-to-apply agent-based model for simulating small-scale coupled human and nature systems in biological conservation hotspots	2023
40	Chichorro, F; Correia, L; Cardoso, P	Biological traits interact with human threats to drive extinctions: A modelling study	2022
41	Chimienti, M; Desforges, JP; Beumer, LT; Nabe-Nielsen, J; van Beest, FM; Schmidt, NM	Energetics as common currency for integrating high resolution activity patterns into dynamic energy budget-individual based models	2020
42	Chliaoutakis, A; Chalkiadakis, G	An Agent-Based Model for Simulating Inter-Settlement Trade in Past Societies	2020
43	Choi, T; Park, S	Theory building via agent-based modeling in public administration research: vindications and limitations	2021
44	Chudzinska, M; Dupont, YL; Nabe-Nielsen, J; Maia, KP; Henriksen, MV; Rasmussen, C; Kissling, WD; Hagen, M; Trojelsgaard, K	Combining the strengths of agent-based modelling and network statistics to understand animal movement and interactions with resources: example from within-patch foraging decisions of bumblebees	2020
45	Chudzinska, M; Nabe-Nielsen, J; Smout, S; Aarts, G; Brasseur, S; Graham, I; Thompson, P; McConnell, B	AgentSeal: Agent-based model describing movement of marine central-place foragers	2021
46	Clark, M; Andrews, J; Hillis, V	A quantitative application of diffusion of innovations for modeling the spread of conservation behaviors	2022
47	Cohen, JJ; Azarova, V; Klockner, CA; Kollmann, A; Lofstrom, E; Pellegrini-Masini, G; Polhill, JG; Reichl, J; Salt, D	Tackling the challenge of interdisciplinary energy research: A research toolkit	2021
48	Collard, P	The flat peer learning agent-based model	2022
49	Collins, AJ; Etemadidavan, S	Humans and the core partition: An agent-based modeling experiment	2022
50	Collins, AJ; Thaviphoke, Y; Tako, AA	Using Strategic Options Development and Analysis (SODA) to understand the simulation accessibility problem	2022
51	Crevier, LP; Salkeld, JH; Marley, J; Parrott, L	Making the best possible choice: Using agent-based modelling to inform wildlife management in small communities	2021
52	Crouse, KN; Desai, NP; Cassidy, KA; Stahler, EE; Lehman, CL; Wilson, ML	Larger territories reduce mortality risk for chimpanzees, wolves, and agents: Multiple lines of evidence in a model validation framework	2022
53	Daly, AJ; De Visscher, L; Baetens, JM; De Baets, B	Quo vadis, agent-based modelling tools?	2022
54	Daniels, JA; Kerr, JR; Kemp, PS	River infrastructure and the spread of freshwater invasive species: Inferences from an experimentally-parameterised individual-based model	2023
55	Datseris, G; Vahdati, AR; DuBois, TC	Agents.jl: a performant and feature-full agent-based modeling software of minimal code complexity	2022
56	Dehkordi, MAE; Lechner, J; Ghorbani, A; Nikolic, I; Chappin, E; Herder, P	Using Machine Learning for Agent Specifications in Agent-Based Models and Simulations: A Critical Review and Guidelines	2023
57	Diaz, SG; DeAngelis, DL; Gaines, MS; Purdon, A; Mole, MA; van Aarde, RJ	Development and validation of a spatially-explicit agent-based model for space utilization by African savanna elephants (Loxodonta africana) based on determinants of movement	2021
58	Djenontin, INS; Ligmann-Zielinska, A; Zulu, LC	Landscape-scale effects of farmers' restoration decision making and investments in central Malawi: an agent-based modeling approach	2022
59	Domingues, CPF; Rebelo, JS; Monteiro, F; Nogueira, T; Dionisio, F	Harmful behaviour through plasmid transfer: a successful evolutionary strategy of bacteria harbouring conjugative plasmids	2022
60	Dominiak, BC; Fanson, BG	Predicting point-source invasion success in the Queensland fruit fly (Bactrocera tryoni): An individual-based modelling approach	2023
61	Du, H; Han, Q; de Vries, B	Modelling energy-efficient renovation adoption and diffusion process for households: A review and a way forward	2022
62	Dubois, T; Pasquaretta, C; Barron, AB; Gautrais, J; Lihoreau, M	A model of resource partitioning between foraging bees based on learning	2021
63	Dur, G; Won, EJ; Han, J; Lee, JS; Souissi, S	An individual-based model for evaluating post-exposure effects of UV-B radiation on zooplankton reproduction	2021
64	Dutta, T; Sharma, S; Meyer, NFV; Larroque, J; Balkenhol, N	An overview of computational tools for preparing, constructing and using resistance surfaces in connectivity research	2022
65	Ekanayake-Weber, M; Swedell, L	An agent-based model of coercive female transfer in a multilevel society	2021
66	El Rahi, J; Weeber, MP; El Serafy, G	Modelling the effect of behavior on the distribution of the jellyfish Mauve stinger (Pelagianoctiluca) in the Balearic Sea using an individual-based model	2020
67	Elizondo, UH; Vogt, M	Individual-based modeling of shelled pteropods	2022

68	Endo, CAK; Skogen, MD; Stige, LC; Hjollo, SS; Vikebo, FB	The effects of spatial and temporal variations in spawning on offspring survival in Northeast Arctic cod	2023
69	Esquivel, KE; Hesselbarth, MHK; Allgeier, JE	Mechanistic support for increased primary production around artificial reefs	2022
70	Estacio, I; Hadfi, R; Blanco, A; Ito, T; Babaan, J	Optimization of tree positioning to maximize walking in urban outdoor spaces: A modeling and simulation framework	2022
71	Estevez-Mujica, CP; Garcia-Diaz, C	Computational Modeling Approaches to Organizational Change	2021
72	Farthing, TS; Lanzas, C	Assessing the efficacy of interventions to control indoor SARS-Cov-2 transmission: An agent-based modeling approach	2021
73	Fedriani, JM; Ayllon, D; Wiegand, T; Grimm, V	Intertwined effects of defaunation, increased tree mortality and density compensation on seed dispersal	2020
74	Fitzpatrick, MC; Lachmuth, S; Haydt, NT	The ODMAP protocol: a new tool for standardized reporting that could revolutionize species distribution modeling	2021
75	Fouladvand, J	Behavioural attributes towards collective energy security in thermal energy communities: Environmental-friendly behaviour matters	2022
76	Furtado, BA	PolicySpace2: Modeling Markets and Endogenous Public Policies	2022
77	Galbraith, ED	Earth system economics: a biophysical approach to the human component of the Earth system	2021
78	Gallagher, CA; Chimienti, M; Grimm, V; Nabe-Nielsen, J	Energy-mediated responses to changing prey size and distribution in marine top predator movements and population dynamics	2022
79	Gallagher, CA; Grimm, V; Kyhn, LA; Kinze, CC; Nabe-Nielsen, J	Movement and Seasonal Energetics Mediate Vulnerability to Disturbance in Marine Mammal Populations	2021
80	Gay, PE; Trumper, E; Lecoq, M; Piou, C	Importance of human capital, field knowledge and experience to improve pest locust management	2021
81	Gegear, RJ; Heath, KN; Ryder, EF	Modeling scale up of anthropogenic impacts from individual pollinator behavior to pollination systems	2021
82	Gibson, M; Pereira, JP; Slade, R; Rogelj, J	Agent-Based Modelling of Future Dairy and Plant-Based Milk Consumption for UK Climate Targets	2022
83	Gibson, M; Slade, R; Pereira, JP; Rogelj, J	Comparing Mechanisms of Food Choice in an Agent-Based Model of Milk Consumption and Substitution in the UK	2021
84	Giordano, R; Manez-Costa, M; Pagano, A; Rodriguez, BM; Zorrilla-Miras, P; Gomez, E; Lopez-Gunn, E	Combining social network analysis and agent-based model for enabling nature-based solution implementation: The case of Medina del Campo (Spain)	2021
85	Gisen, DC; Schutz, C; Weichert, RB	Development of behavioral rules for upstream orientation of fish in confined space	2022
86	Grimm, V	The ODD protocol: An update with guidance to support wider and more consistent use	2020
87	Grimm, V; Johnston, ASA; Thulke, HH; Forbes, VE; Thorbek, P	Three questions to ask before using model outputs for decision support	2020
88	Gunther, G; Clemen, T; Duttmann, R; Schuett, B; Knitter, D	Of Animal Husbandry and Food Production-A First Step towards a Modular Agent-Based Modelling Platform for Socio-Ecological Dynamics	2021
89	Guo, NL; Shi, CC; Yan, M; Gao, X; Wu, F	Modeling agricultural water-saving compensation policy: An ABM approach and application	2022
90	Haase, K; Reinhardt, O; Lewin, WC; Weltersbach, MS; Strehlow, HV; Uhrmacher, AM	Agent-Based Simulation Models in Fisheries Science	2023
91	Haberle, I; Bavcevic, L; Klanjscek, T	Fish condition as an indicator of stock status: Insights from condition index in a food-limiting environment	2023
92	Han, F; Sun, MX; Jia, XX; Klemes, JJ; Shi, F; Yang, D	Agent-based model for simulation of the sustainability revolution in eco-industrial parks	2022
93	Harati, S; Perez, L; Molowny-Horas, R	Promoting the Emergence of Behavior Norms in a Principal-Agent Problem-An Agent-Based Modeling Approach Using Reinforcement Learning	2021
94	Harris, A; Roebber, P; Morss, R	An agent-based modeling framework for examining the dynamics of the hurricane-forecast-evacuation system	2022
95	He, HS; Buchholtz, E; Chen, F; Vogel, S; Yu, CA	An agent-based model of elephant crop consumption walks using combinatorial optimization	2022
96	Hedger, RD; Diserud, OH; Finstad, B; Jensen, AJ; Hendrichsen, DK; Ugedal, O; Naesje, TF	Modeling salmon lice effects on sea trout population dynamics using an individual-based approach	2021
97	Hedger, RD; Sundt-Hansen, LE; Juarez-Gomez, A; Alfredsen, K; Foldvik, A	Exploring sensitivities to hydropeaking in Atlantic salmon parr using individual-based modelling	2023
98	Hernandez-Aguila, A; Garcia-Valdez, M; Merelo-Guervos, JJ; Castanon-Puga, M; Lopez, OC	Using Fuzzy Inference Systems for the Creation of Forex Market Predictive Models	2021
99	Hervey, SD; Rutledge, LY; Patterson, BR; Romanski, MC; Vucetich, JA; Belant, JL; Beyer, DE; Moore, SA; Brzeski, KE	A first genetic assessment of the newly introduced Isle Royale gray wolves (Canis lupus)	2021
100	Holland, A; Gibbons, P; Thompson, J; Roudavski, S	Modelling and Design of Habitat Features: Will Manufactured Poles Replace Living Trees as Perch Sites for Birds?	2023
101	Horn, J; Becher, MA; Johst, K; Kennedy, PJ; Osborne, JL; Radchuk, V; Grimm, V	Honey bee colony performance affected by crop diversity and farmland structure: a modeling framework	2021
102	Innes-Gold, AA; Pavlowich, T; Heinichen, M; McManus, MC; McNamee, J; Collie, J; Humphries, AT	Exploring social-ecological trade-offs in fisheries using a coupled food web and human behavior model	2021
103	Innocenti, E; Detotto, C; Idda, C; Parker, DC; Prunetti, D	An iterative process to construct an interdisciplinary ABM using MR POTATOHEAD: An application to Housing Market Models in touristic areas	2020
104	Iwanaga, T; Wang, HH; Hamilton, SH; Grimm, V; Koralewski, TE; Salado, A; Elsawah, S; Razavi, S; Yang, J; Glynn, P; Badham, J; Voinov, A; Chen, M; Grant, WE; Peterson, TR; Frank, K; Shenk, G; Barton, CM; Jakeman, AJ; Little, JC	Socio-technical scales in socio-environmental modeling: Managing a system-of-systems modeling approach	2021
105	Iwanaga, T; Wang, HH; Koralewski, TE; Grant, WE; Jakeman, AJ; Little, JC	Toward a complete interdisciplinary treatment of scale: Reflexive lessons from socioenvironmental systems modeling	2021
106	Jacobs, M; Remus, A; Gaillard, C; Menendez, HM; Tedeschi, LO; Neethirajan, S; Ellis, JL	ASAS-NANP symposium: mathematical modeling in animal nutrition: limitations and potential next steps for modeling and modelers in the animal sciences	2022
107	Jager, W	Using agent-based modelling to explore behavioural dynamics affecting our climate	2021
108	Janssen, MA; Pritchard, C; Lee, A	On code sharing and model documentation of published individual and agent-based models	2020
109	Jensen, A; Secchi, D; Jensen, TW	A Distributed Framework for the Study of Organizational Cognition in Meetings	2022
110	Johnson, JA; Salemi, C	Agents on a Landscape: Simulating Spatial and Temporal Interactions in Economic and Ecological Systems	2022
111	Johnson, P; McLeod, L; Qin, Y; Osgood, N; Rosengren, L; Campbell, J; Larson, K; Waldner, C	Investigating effective testing strategies for the control of Johne's disease in western Canadian cow-calf herds using an agent-based simulation model	2022
112	Kaffai, M; Heiberger, RH	Modeling non-pharmaceutical interventions in the COVID-19 pandemic with survey-based simulations	2021
113	Kane, A; Ayllon, D; O'Sullivan, RJ; McGinnity, P; Reed, TE	Escalating the conflict? Intersex genetic correlations influence adaptation to environmental change in facultatively migratory populations	2022

114	Kang, YX	Retinex Algorithm and Mathematical Methods Based Texture Detail Enhancement Method for Panoramic Images	2022
115	Kanters, H; Brughmans, T; Romanowska, I	Sensitivity analysis in archaeological simulation: An application to the MERCURY model	2021
116	Kim, H; Cho, CY; Hong, SW	Impact of agent-based simulation on novice architects' workplace design exploration and trade-offs	2023
117	Kim, J; Kim, N	Synthesis of Linked Population Involving Kinship and Influential Ties Using Mate-Search Heuristics	2022
118	Kjaer, LJ; Schauber, EM	The effect of landscape, transmission mode and social behavior on disease transmission: Simulating the transmission of chronic wasting disease in white-tailed deer (Odocoileus virginianus) populations using a spatially explicit agent-based model	2022
119	Knopoff, D; Secchini, V; Terna, P	Cherry Picking: Consumer Choices in Swarm Dynamics, Considering Price and Quality of Goods	2020
120	Koch, J; De Schamphelaere, KAC	Investigating Population-Level Toxicity of the Antidepressant Citalopram in Harpacticoid Copepods Using In Vivo Methods and Bioenergetics-Based Population Modeling	2023
121	Kooi, BW; Kooijman, SALM	A cohort projection method to follow DEB-structured populations with periodic, synchronized and iteroparous reproduction	2020
122	Kruse, M; Meyer, C; Schneekloth, F; Reuter, H	How artificial potential field algorithms can help to simulate trade-offs in movement behaviour of reef fishes	2022
123	Kuehnel, N; Zhang, Q; Staves, C; Moeckel, R	The perfect match? Assessment of excess commute and transport externalities using an agent-based transport model	2023
124	Kurschner, T; Scherer, C; Radchuk, V; Blaum, N; Kramer-Schadt, S	Movement can mediate temporal mismatches between resource availability and biological events in host-pathogen interactions	2021
125	Laatabi, A; Becu, N; Marilleau, N; Amalric, M; Pignon-Mussaud, C; Anselme, B; Beck, E; Bertin, X; Monfort, A; Hayoun, C; Rousseaux, F	LittoSIM-GEN: A generic platform of coastal flooding management for participatory simulation	2022
126	Lamarins, A; Fririon, V; Folio, D; Vernier, C; Daupagne, L; Labonne, J; Buoro, M; Lefevre, F; Piou, C; Oddou-Muratorio, S	Importance of interindividual interactions in eco-evolutionary population dynamics: The rise of demo-genetic agent-based models	2022
127	Lang, DX; Ertsen, MW	Conceptualising and Implementing an Agent-Based Model of an Irrigation System	2022
128	Lange, K; Korevaar, G; Nikolic, I; Herder, P	Actor Behaviour and Robustness of Industrial Symbiosis Networks: An Agent-Based Modelling Approach	2021
129	Leins, JA; Banitz, T; Grimm, V; Drechsler, M	High-resolution PVA along large environmental gradients to model the combined effects of climate change and land use timing: lessons from the large marsh grasshopper	2021
130	Leins, JA; Grimm, V; Drechsler, M	Large-scale PVA modeling of insects in cultivated grasslands: The role of dispersal in mitigating the effects of management schedules under climate change	2022
131	Lemanski, N; Silk, M; Fefferman, N; Udiani, O	How territoriality reduces disease transmission among social insect colonies	2021
132	Lemanski, NJ; Cook, CN; Ozturk, C; Smith, BH; Pinter-Wollman, N	The effect of individual learning on collective foraging in honey bees in differently structured landscapes	2021
133	Li, SN; Hui, BH; Jin, C; Liu, XH; Xu, F; Su, C; Li, T	Considering Farmers' Heterogeneity to Payment Ecosystem Services Participation: A Choice Experiment and Agent-Based Model Analysis in Xin'an River Basin, China	2022
134	Lindau, ST; Makelarski, JA; Kaligotla, C; Abramsohn, EM; Beiser, DG; Chou, CH; Collier, N; Huang, ES; Macal, CM; Ozik, J; Tung, EL	Building and experimenting with an agent-based model to study the population-level impact of CommunityRx, a clinic-based community resource referral intervention	2021
135	Lopez-Jimenez, J; Quijano, N; Vande Wouwer, A	An Agent-Based Crop Model Framework for Heterogeneous Soils	2021
136	Lorig, F; Johansson, E; Davidsson, P	Agent-based Social Simulation of the Covid-19 Pandemic: A Systematic Review	2021
137	Lourie, E; Schiffner, I; Toledo, S; Nathan, R	Memory and Conformity, but Not Competition, Explain Spatial Partitioning Between Two Neighboring Fruit Bat Colonies	2021
138	MacPherson, B; Scott, R; Gras, R	Using individual-based modelling to investigate a pluralistic explanation for the prevalence of sexual reproduction in animal species	2023
139	MacPherson, B; Scott, R; Gras, R	Using individual-based modelling to investigate the possible role that the Red Tooth effect plays in maintaining sexual reproduction	2021
140	Madeira, LM; Furtado, BA; Dill, AR	VIDA: A Simulation Model of Domestic Violence in Times of Social Distancing	2021
141	Magliocca, NR	Agent-Based Modeling for Integrating Human Behavior into the Food-Energy-Water Nexus	2020
142	Malanson, GP; Testolin, R; Pansing, ER; Jimenez-Alfaro, B	Area, environmental heterogeneity, scale and the conservation of alpine diversity	2023
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144	Masison, J; Mendes, P	Modeling the iron storage protein ferritin reveals how residual ferrihydrite iron determines initial ferritin iron sequestration kinetics	2023
145	McDonald, GW; Bradford, L; Neapetung, M; Osgood, ND; Strickert, G; Waldner, CL; Belcher, K; McLeod, L; Bharadwaj, L	Case Study of Collaborative Modeling in an Indigenous Community	2022
146	Medeiros-Sousa, AR; Laporta, GZ; Mucci, LF; Marrelli, MT	Epizootic dynamics of yellow fever in forest fragments: An agent-based model to explore the influence of vector and host parameters	2022
147	Meier, L; Brauns, M; Grimm, V; Weitere, M; Frank, K	MASTIFF: A mechanistic model for cross-scale analyses of the functioning of multiple stressed riverine ecosystems	2022
148	Milles, A; Dammhahn, M; Grimm, V	Intraspecific trait variation in personality-related movement behavior promotes coexistence	2020
149	Milles, A; Dammhahn, M; Jeltsch, F; Schlaegel, U; Grimm, V	Fluctuations in Density-Dependent Selection Drive the Evolution of a Pace-of-Life Syndrome Within and Between Populations	2022
150	Moradi, S; Nejat, A	RecovUS: An Agent-Based Model of Post-Disaster Household Recovery	2020
151	Moraitis, G; Sakki, GK; Karavokiros, G; Nikolopoulos, D; Tsoukalas, I; Kossieris, P; Makropoulos, C	Exploring the Cyber-Physical Threat Landscape of Water Systems: A Socio-Technical Modelling Approach	2023
152	Mori, K; Massolo, A; Marceau, D; Stefanakis, E	Modelling the epidemiology of zoonotic parasites transmitted through a predator-prey system in urban landscapes: The Calgary Echinococcus multilocularis Coyote Agent-based model (CEmCA) br	2023
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154	Munoz, GA; Gil-Costa, V; Marin, M	Efficient simulation of natural hazard evacuation for seacoast cities	2022
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156	Mysterud, A; Viljugrein, H; Rolandsen, CM; Belsare, AV	Harvest strategies for the elimination of low prevalence wildlife diseases	2021
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161	Niu, LH; Ou, SY	Usability evaluation of two new presentation modes of scientific articles for academic reading	2022
162	Noeldeke, B; Winter, E; Ntawuhiganayo, EB	Representing human decision-making in agent-based simulation models: Agroforestry adoption in rural Rwanda	2022
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164	Nolzen, H; Brugger, K; Reichold, A; Brock, J; Lange, M; Thulke, HH	Model-based extrapolation of ecological systems under future climate scenarios: The example of Ixodes ricinus ticks	2022
165	Nutaro, J; Ozmen, O	Race conditions and data partitioning: risks posed by common errors to reproducible parallel simulations	2023
166	Panneerselvam, T; Arun, CJ	Bias-driven marketing that instigates pledging to a crowdfunding campaign: An experimental consideration of behavioral anomalies	2022
167	Peck, SL; Heiss, A	Can constraint closure provide a generalized understanding of community dynamics in ecosystems?	2021
168	Peng, YCN; Lopez, JMR; Santos, AP; Mobeen, M; Scheffran, J	Simulating exposure-related human mobility behavior at the neighborhood-level under COVID-19 in Porto Alegre, Brazil	2023
169	Peralta, G; Webber, CJ; Perry, GLW; Stouffer, DB; Vazquez, DP; Tylianakis, JM	Scale-dependent effects of landscape structure on pollinator traits, species interactions and pollination success	2023
170	Perez, AZ; Bone, C; Stenhouse, G	Simulating multi-scale movement decision-making and learning in a large carnivore using agent-based modelling	2021
171	Perry, GLW	How far might plant-eating dinosaurs have moved seeds?	2021
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173	Pietzsch, BW; Peter, FJ; Berger, U	The Effect of Sanitation Felling on the Spread of the European Spruce Bark Beetle-An Individual-Based Modeling Approach	2021
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175	Pili, AN; Tingley, R; Chapple, DG; Schumaker, NH	virToad: simulating the spatiotemporal population dynamics and management of a global invader	2022
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177	Pirotta, E	A review of bioenergetic modelling for marine mammal populations	2022
178	Planque, B; Aarflot, JM; Buttay, L; Carroll, J; Fransner, F; Hansen, C; Husson, B; Langangen, O; Lindstrom, U; Pedersen, T; Primicerio, R; Sivel, E; Skogen, MD; Strombom, E; Stige, LC; Varpe, O; Yoccoz, NG	A standard protocol for describing the evaluation of ecological models	2022
179	Planque, B; Favreau, A; Husson, B; Mousing, EA; Hansen, C; Broms, C; Lindstrom, U; Sivel, E	Quantification of trophic interactions in the Norwegian Sea pelagic food-web over multiple decades	2022
180	Platas-Lopez, A; Guerra-Hernandez, A; Quiroz-Castellanos, M; Cruz-Ramirez, N	A survey on agent-based modelling assisted by machine learning	2023
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182	Polhill, G; Edmonds, B	Cognition and hypocognition: Discursive and simulation-supported decision-making within complex systems*	2023
183	Preuss, TG; Agatz, A; Goussen, B; Roeben, V; Rumkee, J; Zakharova, L; Thorbek, P	The BEEHAVE(ecotox) Model-Integrating a Mechanistic Effect Module into the Honeybee Colony Model	2022
184	Ravaioli, G; Domingos, T; Teixeira, RFM	A Framework for Data-Driven Agent-Based Modelling of Agricultural Land Use	2023
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187	Reinhard, S; Naranjo, MA; Polman, N; Hennen, W	Modelling choices and social interactions with a threshold public good: Investment decisions in a polder in Bangladesh	2022
188	Roeleke, M; Schlagel, UE; Gallagher, C; Pufelski, J; Blohm, T; Nathan, R; Toledo, S; Jeltsch, F; Voigt, CC	Insectivorous bats form mobile sensory networks to optimize prey localization: The case of the common noctule bat	2022
189	Rohwader, MS; Jeltsch, F	Foraging personalities modify effects of habitat fragmentation on biodiversity	2022
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191	Sakiyama, T	Spatial inconsistency of memorized positions produces different types of movements	2023
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197	Schoedl, I; Odemer, R; Becher, MA; Berg, S; Otten, C; Grimm, V; Groeneveld, J	Simulation of Varroa mite control in honey bee colonies without synthetic acaricides: Demonstration of Good Beekeeping Practice for Germany in the BEEHAVE model	2022
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199	Shin, H	Quantifying the health effects of exposure to non-exhaust road emissions using agent-based modelling (ABM)	2022
200	Smaldino, PE	How to Translate a Verbal Theory Into a Formal Model	2020
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205	Squazzoni, F; Polhill, JG; Edmonds, B; Ahrweiler, P; Antosz, P; Scholz, G; Chappin, E; Borit, M; Verhagen, H; Giardini, F; Gilbert, N	Computational Models that Matter During a Global Pandemic Outbreak: A Call to Action	2020
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211	Takahashi, A; Ban, SYH; Papa, RDS; Tordesillas, DT; Dur, G	Cumulative reproduction model to quantify the production of the invasive species Arctodiaptomus dorsalis (Calanoida, Copepoda)	2023
212	Tardy, O; Lenglos, C; Lai, SD; Berteaux, D; Leighton, PA	Rabies transmission in the Arctic: An agent-based model reveals the effects of broad-scale movement strategies on contact risk between Arctic foxes	2023
213	Tardy, O; Vincenot, CE; Bouchard, C; Ogden, NH; Leighton, PA	Context-dependent host dispersal and habitat fragmentation determine heterogeneity in infected tick burdens: an agent-based modelling study	2022
214	Teran, O; Leger, P; Lopez, M	Modeling and simulating Chinese cross-border e-commerce: an agent-based simulation approach	2022
215	Thompson, J; McClure, R; Blakely, T; Wilson, N; Baker, MG; Wijnands, JS; De Sa, TH; Nice, K; Cruz, C; Stevenson, M	Modelling SARS-CoV-2 disease progression in Australia and New Zealand: an account of an agent-based approach to support public health decision-making	2022
216	Thurner, SD; Converse, SJ; Branch, TA	Modeling opportunistic exploitation: increased extinction risk when targeting more than one species	2021
217	Tracy, M; Gordis, E; Strully, K; Marshall, BDL; Cerda, M	Applications of Agent-Based Modeling in Trauma Research	2022
218	Troost, C; Huber, R; Bell, AR; van Delden, H; Filatova, T; Le, QB; Lippe, M; Niamir, L; Polhill, JG; Sun, ZL; Berger, T	How to keep it adequate: A protocol for ensuring validity in agent-based simulation	2023
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220	Twumwaa, TE; Justice, N; Robert, V; Itamar, M	Application of decision analytical models to diabetes in low- and middle-income countries: a systematic review	2022
221	Van Buskirk, AN; Rosenberry, CS; Wallingford, BD; Domoto, EJ; McDill, ME; Drohan, PJ; Diefenbach, DR	Modeling how to achieve localized areas of reduced white-tailed deer density	2021
222	Van Roekel, G; Smit, M	Herd behaviour and the emergence of clusters	2022
223	Vaugeois, M; Venturelli, PA; Hummel, SL; Forbes, VE	Population modeling to inform management and recovery efforts for lake sturgeon, Acipenser fulvescens	2022
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226	Verhagen, P; de Kleijn, M; Joyce, J	Different Models, Different Outcomes? A Comparison of Approaches to Land Use Modeling in the Dutch Limes	2021
227	Vermeer, WH; Smith, JD; Wilensky, U; Brown, CH	High-Fidelity Agent-Based Modeling to Support Prevention Decision-Making: an Open Science Approach	2022
228	Vernon-Bido, D; Collins, A	Finding Core Members of Cooperative Games Using Agent-Based Modeling	2021
229	Verrier, E; Baudry, E; Bessa-Gomes, C	Modelling the effects of the repellent scent marks of pollinators on their foraging efficiency and the plant-pollinator community	2021
230	Vieira, LS; Laubenbacher, RC	Computational models in systems biology: standards, dissemination, and best practices	2022
231	Vieira, VMNCS; Engelen, AH; Huanel, OR; Guillemin, ML	An Individual-Based Model of the Red Alga Agarophyton chilense Unravels the Complex Demography of Its Intertidal Stands	2022
232	Vinyals, M; Sabbadin, R; Couture, S; Sadou, L; Thomopoulos, R; Chapuis, K; Lesquoy, B; Taillandier, P	Toward AI-designed innovation diffusion policies using agent-based simulations and reinforcement learning: The case of digital tool adoption in agriculture	2023
233	Vojnovic, I; Ligmann-Zielinska, A; LeDoux, TF	The dynamics of food shopping behavior: Exploring travel patterns in low-income Detroit neighborhoods experiencing extreme disinvestment using agent-based modeling	2020
234	Wang, R; Ye, ZN; Lu, MJ; Hsu, SC	Understanding post-pandemic work-from-home behaviours and community level energy reduction via agent-based modelling	2022
235	Watson, JW; Boyd, R; Dutta, R; Vasdekis, G; Walker, ND; Roy, S; Everitt, R; Hyder, K; Sibly, RM	Incorporating environmental variability in a spatially-explicit individual-based model of European sea bass	2022
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237	Williams, TG; Brown, DG; Agrawal, A; Guikema, SD	Let the farmer decide: examining smallholder autonomy in large-scale land acquisitions with an agent-based model	2021
238	Williams, TG; Brown, DG; Guikema, SD; Logan, TM; Magliocca, NR; Muller, B; Steger, CE	Integrating Equity Considerations into Agent-Based Modeling: A Conceptual Framework and Practical Guidance	2022
239	Wilsdorf, P; Wolpers, A; Hilton, J; Haack, F; Uhrmacher, A	Automatic Reuse, Adaption, and Execution of Simulation Experiments via Provenance Patterns	2023
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241	Wolf, S; Furst, S; Geiges, A; Laublichler, M; Mielke, J; Steudle, G; Winter, K; Jaeger, C	The Decision Theatre Triangle for societal challenges-An example case and research needs	2023
242	Yletyinen, J; Perry, GLW; Burge, OR; Mason, NWH; Stahlmann-Brown, P	Invasion landscapes as social-ecological systems: Role of social factors in invasive plant species control	2021
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246	Zhang, JX; Robinson, DT	Replication of an agent-based model using the Replication Standard	2021
247	Zoller, N; Morgan, JH; Schroder, T	Modeling Interaction in Collaborative Groups: Affect Control within Social Structure	2021
248	Zuo, Y; Zhao, XG	Effects of herding behavior of tradable green certificate market players on market efficiency: insights from heterogeneous agent model	2021

The Review Literature can be found here: `https://www.jasss.org/27/4/1/literature_review.pdf`

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