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COMMENT

Hierarchy of hypotheses or cascade of predictions? A comment on Heger et al. (2013)

Alejandro G. Farji-Brener, Sabrina Amador-Vargas

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The only way to test hypotheses is by evaluating their consequences. Since a hypothesis is an explanation of how nature works, it can be tested through the formulation of outcomes expected assuming the proposed hypothesis is true, and contrasting those predictions with the obtained results. Therefore, hypothesis and predictions are intrinsically different concepts. Hypotheses are ideas; predictions are expected results. Predictions are deduced from hypotheses, but it is unlikely to deduce a hypothesis from a prediction. Regardless of these conceptual differences, ecologists often formulate predictions but erroneously state them as hypothesis (Farji-Brener 2003). We believe that this is the case in the work of Heger et al. (2013). Here, we point out the confusion between hypotheses and predictions, highlight the importance of an adequate use of these terms, and propose the hierarchy-of-expected outcomes approach as an alternative to the hierarchy-of-hypotheses approach.

In the Heger et al. (2013) proposal, the authors highlight the potential of the hierarchy-of-hypotheses approach (hereafter, HoH) for testing the validity of biological hypotheses. Specifically, this method is used in the thorough study of Heger and Jeschke (2014) to evaluate the enemy release hypothesis (hereafter, ERH), a key idea in invasion ecology, which postulates that "*the absence of enemies in the exotic range is a cause of invasion success.*" The HoH is a method that proposes partitioning a single major hypothesis in a hierarchy of sub-hypotheses. The general hypothesis is positioned at the top level, and it branches into more specific sub-hypotheses which also branch into even more specific sub-hypothesis. In this way, HoH integrates broad ideas as well as specific ones, which unify empirical tests under a common framework. The approach itself sounds promising, but its application facilitates the already common confusion between hypotheses and predictions.

The classification of sub-hypotheses in Heger et al. (2013) and Heger and Jeschke (2014) as it is presented ends up as a tool for organizing published results rather than a drawing-up of real hypotheses. To exemplify their method, the authors classified the sub-hypotheses of ERH according to three criteria: (a) indicator of enemy release, (b) type of comparison, and (c) type of enemies. However, these criteria are not real explanations derived from ERH of why invaders are successful. Criteria (a) and (c) focus on the response variable (e.g., leaf damage, performance of alien species, abundance or diversity of specialist or generalist natural enemies, etc.) and (b) focus on "treatments" (e.g., comparison between alien vs. native species, with or without enemies, etc.). In fact, the proposed sub-hypotheses are indeed predictions, because they are expected results rather than ideas. For example, the first subset of "hypotheses" (first branch level) is: "less damage by enemies," "less infestation by enemies," and "enhanced performance" (see Fig. 1 in Heger et al. 2013, and Heger and Jeschke 2014); clearly, all those are expected results under the assumption that the ERH is true. The second-order level of "sub-hypotheses" specifies the treatments or units of comparison used in those predictions, but again, those are not potential explanations, as hypotheses should be. For instance, the second-level hypotheses for the first-level "leaf damage by enemies" specify whether the comparison was between alien vs. natives, alien in native vs. exotic range, etc. In other words, all these statements are specific predictions of the ERH (e.g., less damage by enemies in alien vs. natives, etc.), rather than sub-hypotheses.

The confusion between hypotheses and predictions is more common than thought: about 30 % of ecology articles

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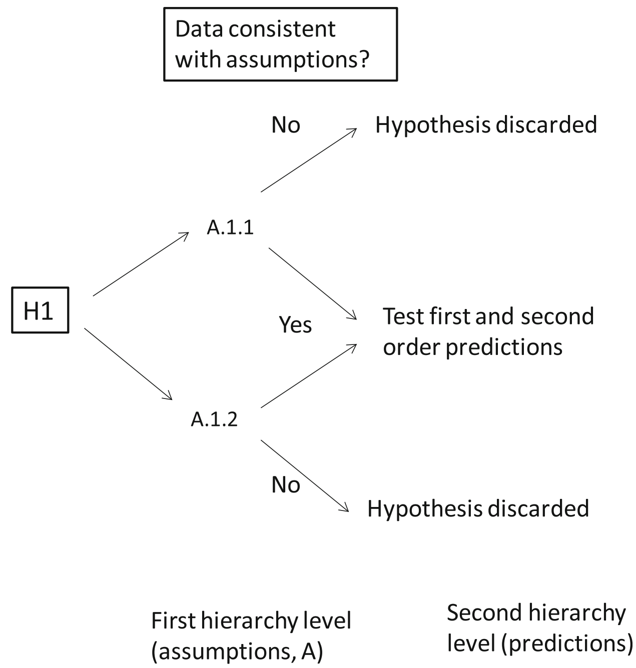

Fig. 1 Scheme of the hierarchy-of-expected outcomes approach (HoEOs). A hypothesis branches into different hierarchies of expected outcomes, which should be tested in order. If key assumptions are not supported by data, then testing outcomes at the lower level is worthless, and the original hypothesis could be rejected. Only one hypothesis and two assumptions are shown for simplicity

published in top journals used hypothesis and predictions as synonymous terms (Farji-Brener 2003). This confusion is not trivial, because it violates the principles of the hypothetic-deductive method. As discussed earlier, proposed explanations can only be tested by evaluating the expected results. Formulating predictions that lack explicit mention of the hypothesis they derived from impedes readers to assess the deductive capacity of the author. Specifically, omitting explicit hypotheses in the text (or replacing them with predictions) complicates its interpretation because readers ignore the tested explanation. Thus, it is impossible to critically assess whether relevant predictions were evaluated or whether non-mentioned alternative hypotheses are also valid. To avoid these complications, we propose the hierarchy-of-expected outcomes approach (HoEO) as an alternative to the hierarchy-of-hypotheses approach.

The HoEO method follows the general principles of the HoH but using expected outcomes (i.e., assumptions and predictions) instead of sub-hypotheses. Each hypothesis branches in expected results with different hierarchies based on their ability to undermine the proposed hypothesis (Fig. 1.). If data do not support key assumptions (i.e., first-order expected outcomes), it is senseless to test specific predictions (i.e., second-order expected outcomes). Conversely, if assumptions are supported by data, we can proceed to test specific predictions, which may also branch in lower levels of hierarchy, relevance, or peculiarity depending on the topic. It is important to clarify that confirming assumptions does not necessarily verify the validity of the proposed hypothesis, but it is an essential step before continuing with the next level of expected outcomes. In other words, it is unreasonable to test specific predictions when key assumptions of the hypothesis are not supported by data. Returning to the ERH example, the first branch of assumptions could include: (a) a negative relationship between damage and fitness, and (b) the absence of natural enemies in the exotic range. Clearly, if damage by natural enemies does not reduce fitness or if natural enemies are present in the exotic range, the "absence" of enemies cannot be a cause of invasion success, and no further testing is needed. The second-level branch (i.e., predictions) may include those described as sub-hypothesis in Heger et al. (2013) and Heger and Jeschke (2014), for example, less damage in alien versus natives, in alien in native versus exotic ranges, etc. Specific predictions regarding type of damage, specificity of enemies, and proxies for fitness may be located at lower level branches.

This hierarchy-of-expected outcomes approach offers some conceptual and logistical advantages. First, it follows the hypothetic-deductive method, which postulates that ideas can only be proved through their consequences (but not vice versa) and that the strongest predictions are those with the best potential to discard the hypothesis they derived from. Second, authors must explicitly use their deductive abilities combined with the need for a deeper understanding of the natural history of the studied organism to formulate relevant predictions. Third, the hierarchy scheme avoids extra work: it is worthless to invest energy and time testing second-order expected outcomes when data did not support key assumptions. Fourth, this conceptual framework allows contrasting alternative hypotheses more clearly. A priori assignation of different weights to predictions within each hypothesis may help discriminate which hypothesis explains better a natural pattern. The system for weighting predictions and the decision of which hypothesis has more support may follow the method proposed by Heger and Jeschke (2014) to weight "sub-hypotheses". We agree that general, broad hypotheses may be subdivided into more specific ones, as long as sub-hypotheses are not predictions. Also, it is clearer to contrast hypotheses by testing their assumptions and predictions to avoid conceptual confusions and to improve logistics of data collection. We propose that the hierarchy-of-outcomes approach could be a simple, practical, and useful tool to better understand how nature works.

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Alejandro G. Farji-Brener (✉)
Address: Laboratorio Ecotono, CRUB-Universidad Nacional del Comahue, INIBIOMA-CONICET. Pasaje Gutiérrez 1125, 8400 Bariloche, Argentina.
e-mail: alefarji@yahoo.com

Sabrina Amador-Vargas
Address: Department of Integrative Biology, University of Texas at Austin, Austin, TX, USA.
e-mail: samadorv@utexas.edu