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The more the merrier: Multi-species experiments in ecology

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Abstract

A major objective in ecology is to find general patterns, and to establish the rules and underlying mechanisms that generate those patterns. Nevertheless, most of our current insights in ecology are based on case studies of a single or few species, whereas multi-species experimental studies remain rare. We underline the power of the multi-species experimental approach for addressing general ecological questions, e.g. on species environmental responses or on patterns of among- and within-species variation. We present simulations that show that the accuracy of estimates of between-group differences is increased by maximizing the number of species rather than the number of populations or individuals per species. Thus, the more species a multi-species experiment includes, the more powerful it is. In addition, we discuss some inevitable methodological challenges of multi-species experiments. While we acknowledge the value of single- or few-species experiments, we strongly advocate the use of multi-species experiments for addressing ecological questions at a more general level.

Zusammenfassung

Eines der wichtigsten Ziele in der Ökologie ist es, allgemeine Muster zu erkennen und die Mechanismen zu verstehen, die solchen Mustern zugrunde liegen. Nichtsdestotrotz basieren die meisten neueren Erkenntnisse in der Ökologie auf Untersuchungen einzelner oder weniger Arten, während experimentelle Studien mit vielen Arten nach wie vor selten sind. Wir unterstreichen die Bedeutung von Mehrartenexperimenten für die Beantwortung grundlegender ökologischer Fragen, z.B. zur Reaktion von Arten auf Umweltwandel, oder zu Mustern zwischen- und innerartlicher Variation. Wir präsentieren Simulationsergebnisse, die

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zeigen, dass Schätzungen genereller Unterschiede zwischen Artengruppen vor allem durch eine Maximierung der Artenzahl verbessert werden, während Änderungen in der Anzahl von Populationen oder Individuen kaum Einfluss haben. Je mehr Arten ein Mehrartenexperiment umfasst, desto aussagekräftiger und statistisch belastbarer ist es. Wir diskutieren einige methodische Herausforderungen bei Mehrartenexperimenten. Obwohl wir den Wert ökologischer Fallstudien mit einzelnen oder wenigen Arten anerkennen, empfehlen wir ausdrücklich den Einsatz von Mehrartenexperimenten zur allgemeingültigen Beantwortung wichtiger ökologischer Fragen.

Keywords: Ecological experiments; Generalism; Meta-analysis; Multiple species; Precision; Realism; Simulations

The precision-generalism-realism trade-off

Many insights in ecology are initially based on case studies restricted to single or few species, or to single populations or genotypes. However, a major objective in ecology is to find general patterns, and to establish rules and mechanisms generating them. Many ecologists generalize the results of case studies, despite the fact that these studies might not be representative for the majority of species and conditions. As a consequence, many of our current insights in ecology might not be as general as they claim to be.

Ecological studies are inevitably constrained by a 3-way trade-off involving precision, generalism and realism (Fig. 1; Levins, 1966; Guisan & Zimmermann, 2000). Although methodological advances and large logistic efforts may partly relieve this constraint, we still have to decide for each experiment whether we want very precise results by focusing on a single species, more general results by using large numbers of species (and many different environments), to conduct the experiment under the most realistic conditions (i.e. in the field) or a compromise. There is a need for all types of studies filling different sectors of the precision-generalism-realism trade-off triangle (Fig. 1). However, the search for general patterns, rules and mechanisms would progress much more rapidly if multi-species experiments (Fig. 2) would be used more frequently. Here, we discuss the types of questions that require a multi-species approach, the number of species required in such experiments, and some methodological issues. Although we mainly use plant examples, the points we make are equally relevant for studies of other taxonomic groups.

Questions requiring a multi-species approach

The conclusions drawn from a study are only valid for the statistical population from which the study objects were sampled. This implies that if, for example, we want to know how Central European species will respond to climate warming, we should grow a random sample of these species – instead of just our favorite study species – under ambient and elevated temperatures. Thus, questions on general species responses require multi-species experiments.

As species vary tremendously in success, habitat preferences and other characteristics, major questions in ecology ask whether this variation maps onto particular groups of species or how it correlates with other species characteristics. One example is the question of what differentiates invasive species from non-invasive species. Furthermore, as there is also variation among populations and genotypes within species, many other major questions in ecology address whether particular patterns of within-species differences are consistent across species. A typical example here would be the question of what differentiates populations in the center of the range from those at the margins. Multi-species experiments can therefore provide more general answers to questions concerning both within- and among-species variation.

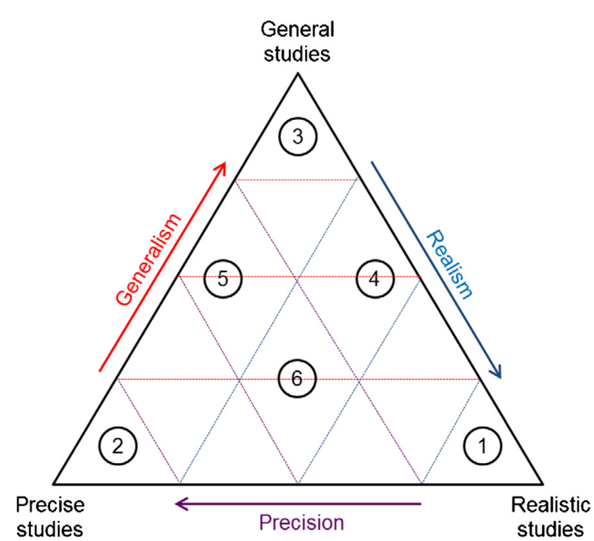

Fig. 1. The trade-off between precision, generalism and realism which constrains the design of ecological studies. The definitions of precision, generalism and realism are relative rather than absolute, and can be context dependent. However, if precision of species estimates is determined by the number of populations, generalism by the number of species and realism by whether the experiment was done under artificial or field conditions, the encircled numbers in the plot could correspond to the following types of studies: (1) one species, one population, field site; (2) one species, 50 populations, growth room; (3) 50 species, one population each, growth room; (4) 25 species, one population each, common garden; (5) 25 species, 10 populations each, growth room; (6) 10 species, 10 populations each, common garden.