Description of Animal Body Size Causal Knowledge Analysis Example

From: Grace, J.B. Call for a paradigm shift from statistical causal inference to multi-evidence causal investigation. (in review)

An example of mechanistic causal inference

I begin this presentation by illustrating mechanistic causal inference in order to establish perspective and to introduce necessary terminology. I first draw from a finding published in the Proceeding of the National Academy of Sciences (Fig. 1A). The authors of that study used camera traps and fecal nutrient analyses in African savannas to determine the degree to which variations in the size of herbivorous animals (Fig. 1B) influence the ratios of mineral nutrients they return to the ecosystem. The authors concluded from this study that local environmental conditions that influence the average body size of herbivores foraging in an area (such as predation risk and type of forage) in turn influence the ratios at which nutrients are returned to the ecosystem. In essence, the authors (*28*) implied the existence of a causal relationship between animal body size and phosphorus retention based on mechanistic knowledge. As will be explained below, the observed correlation does not qualify as a traditional causal effect since the data and analysis techniques fail to meet the necessary requirements for statistical causal inference (*21*).

If the association in Fig. 1A does not qualify as a statistical causal effect, how can we justify a causal interpretation? Until very recently, foundational principles and operational procedures did not exist for this challenge (*23*). *Causal knowledge analysis* refers to the documentation of mechanistic and other non-statistical evidence supporting causal interpretations. This example used a *causal knowledge diagram* (Fig. 1C) as a device to aid in documenting the evaluation. The causal knowledge diagram for this example outlines a mechanistic explanation for how animal body size can influence phosphorus retention and excretion. Causal knowledge analysis also involves characterization of the expected behavior of the described mechanisms based on the attributes of the structures and processes making up the mechanistic machinery.

The underlying mechanism driving the observed relationship is well known and understood. Galileo (Fig. 1D) proposed back in the year 1638 (*29*, *30*) that larger animals would have to allocate a greater fraction of their body mass to skeletal materials due to biophysical demands and constraints. Since bone strength is proportional to cross-sectional area (a square function) and body mass is proportional to its volume (a cube function), larger animals will require a greater proportional investment in skeletal materials to withstand the physical stresses they experience. Subsequent global analyses (*31*) have led to a general equation that permits us to estimate the % skeletal mass for the animals observed in the study by LeRoux et al. (*28*) (Fig. 1E). Skeletal material is primarily composed of phosphorus compounds, resulting in differential P retention and a decrease in P excretion by larger animals (Fig. 1F). Grace (*23*) provides a summary of the (a) sufficiency, (b) reliability, (c) exactness, and (d) generality of the mechanism described obtained from an in-depth causal knowledge analysis. A key conclusion from that analysis is, "Strong transportability for the discussed mechanism has been demonstrated for a wide range of animals and situations by (*32*, *33*, *34*). This confirms the general principle that biophysical constraints on the traits of organisms provide highly transportable causal knowledge." Scientists may recognize that causal knowledge analysis is a formalization of the process scientists have long relied upon informally to support causal interpretations, though with a deeper consideration of the mechanistic basis of causation and the causal methods literature.