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Additional Thoughts on Rigor in Wildlife Science:Unappreciated Impediments

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Traditionally, most scientists accept reductionist and mechanistic approaches as the rigorous way to do science. Sells et al. (2018) recently raised the argument about reliability in wildlife science. Chamberlin (1890), Platt (1964), Romesburg (1981, 1991, 2009), and Williams (1997) were rightly referenced as very influential papers. My intention in this paper is not to refute the essence of the Sells et al. (2018) paper but to add seldom addressed, but important aspects that influence the attainment of rigor and certainty in wildlife studies. The elements of a rigorous approach (i.e., strong inference) as described by (Platt 1964) included devising alternative hypotheses, devising ≥1 crucial experiments that will exclude ≥1 of the hypotheses, and carrying out the experiment to get a clean result. The process was then repeated using logical inductive trees (i.e., a continually bifurcated statement hypotheses approach) to obtain the essential cause for the effect. Platt (1964) agreed with Popper (1959) that science advanced only by disproof. He argued that this was a hard doctrine and leads to disputations between scientists, but that Chamberlin's (1890) method of multiple working hypotheses helped to remove that difficulty.

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Platt (1964) emphasized inductive inference and crucial and critical experiments whereby alternate hypotheses are refuted. Romesburg (1981) explained that in wildlife biology, that induction (reliable associations) and retroduction (developing hypotheses) were the basis for almost all wildlife research but were not sufficient. He proposed the hypothetical-deductive (H-D) method as a more reliable approach. Citing Harvey (1969) and Popper (1962), Romesburg (1981:294) explained that "Starting with the research hypothesis, usually obtained by retroduction, predictions are made about other classes of facts that should be true if the research hypothesis is actually true." The hypothesis is then tested indirectly by using logic to deduce one or more test consequences (Romesburg 2014). Data are then collected in a statistical framework. Romesburg (1981) distinguished between a research hypothesis (i.e., a conjecture about some process) versus a statistical hypothesis (i.e., a conjecture about classes of facts encompassed by the process). Williams (1997) clearly explained the differences between necessary and sufficient causation and gave examples of the coherent logic both entailed. He summarized that the science endeavor included theory, hypotheses, predictions, observations, and comparison of predictions against data, and argued that inductive and deductive logic were required for testing hypotheses. Importantly, Williams (1997:1014) recognized that wildlife biology often involves simultaneous complementary explanatory factors, requiring "the framing of many scientifically interesting issues about cause and effect in terms of the relative contribution of multiple causal factors." Over the years, many others have addressed the issue of rigor and reliability in the *Journal of Wildlife Management* (*JWM*) and the *Wildlife Society Bulletin* (*WSB*) either directly (McNab 1983, Eberhardt 1988, Anderson 2001) or indirectly (Steidl et al. 1997, Guthery et al. 2001). This is not a complete list and is limited primarily to *JWM* and *WSB* but gives an idea of the wide interest in achieving reliable results from wildlife studies.

Sells et al. (2018) listed 6 steps that defined scientific rigor in wildlife studies, largely following Platt (1964) and Romesburg (1981). Further, they gave an accounting of the historical and logical roots of scientific methodology. Significantly, they argued persuasively for developing multiple working hypotheses and using the syllogistic logic of modus tollens (i.e., denying the consequent [Table 1]). Sells et al. (2018:7) stated that studies that "subject a priori hypotheses to falsification produce the most reliable knowledge." Gula and Theuerkauf (2018:1565) countered, explaining the importance of observations and descriptive studies, and arguing that "In wildlife science, however, we are dealing with systems that are complex with large numbers of elements that influence each other. Therefore, it is difficult to formulate hypotheses of universal character that, if proven and established as theory, can provide reliable predictions." Additionally, Loehle (1987) suggested that many questions in ecology (e.g., the what, when, and where questions) constituted observational or descriptive studies and did not lend themselves easily to the H-D methods. Mitchell et al. (2018) responded to Gula and Theuerkauf, suggesting that they misunderstood the main points made by Sells et al. (2018).

Platt (1964) correctly observed that criticism or challenges to scientific methodology strikes at our respective egos. It is not my intention to challenge the views presented in Sells et al. (2018) or Gula and Theuerkauf (2018). Rather, my objective in this paper is to suggest that there are important aspects of the 'rigor equals reliability' argument that are seldom addressed, but that go to the heart of the question of rigor and certainty in wildlife studies. They include an enhanced explanation of syllogistic logic that underlays the classical philosophy of science, the more complex aspects of causality not often appreciated, and the often overlooked mismatch between the complexity of ecology versus the analytical approach we are forced to use (e.g., number systems). I argue that these concerns should mitigate our certainty that any approach to understand ecology is best or exact. Rather, in dealing with the limiting approaches we have available, wildlife biologists face serious complexities that interfere with obtaining the rigor and reliability we seek in field studies. Hence, statements arguing for a specific methodology as providing certainty and reliability of results without the necessary qualifiers are suspect. I argue that a better approach is to treat study results as working hypotheses that are parts of a larger n-dimensional puzzle that is subject to spatial and temporal dynamics and hence subject to change, given additional data.

UNDERLYING ASSUMPTIONS

Syllogistic Logic

There are2 consistent syllogistic arguments: modus tollens (the logical structure that denies the consequence), and modus ponens (the logical structure that affirms the antecedent; Copi and Cohen 2005). There are also 2 illogical arguments that may be mistaken or confused with logical arguments. The illogical arguments are termed affirming the consequent, and denying the antecedent. The terms antecedent and consequent refer to the order of the terms of the syllogistic argument (Table 1). Whatever consistent syllogistic argument is made, its usefulness relies on the correctness of the logical construction and importantly on the stated premises themselves. I agree with Sells et al. (2018:7) that “Humans are incapable of perceiving and understanding full reality so can only use science to evaluate a simplified version of it.” Seldom can 1 syllogistic statement, however correctly stated, account for the complexity found in ecological studies.

Falsifiability

Popper’s (1959) emphasis on falsifiability has been used as the demarcation between science and something else (Pickett et al. 1994) and was a reaction to the flaws of logical positivism, an influential Viennese school of philosophy (Boyd 1991). As originally conceived, the prerequisites for falsifiability were universality and simple causality. "Any exception to a suppposed literally universal statement meant that (it) was not universal" (Pickett et al. 1994:15). Simple causality implies a single cause for the observed effect. Indeed, we have borrowed the classical philosophy of science from physics. The laws of classical physics were considered to be literally universal, "applying to all heavenly bodies at any time and place in the universe" (Pickett et al. 1994:15). In general, wildlife biologists recognize that laws or concepts in ecology are probabilistic, seldom simple, and almost never universal.

THE NATURE OF CAUSALITY

Wildlife biologists usually understand and examine causality as a simple binary cause – effect dyad. However, Korzybsky (1958:217) argued that "the term cause-effect represents a two term relation, and, as such, is a primitive generalization *never* to be found in this world, as all events are *serially* related in a most complex way, independent of our way of speaking about them". Wright (1979:N111) argued that "We think primarily in a sequential fashion, thus distorting Nature, because of our inability to cope with the complexity that actually exists". She explained that the word cause suggests a simplistic relationship that is inappropriate for 3 reasons. First, it suggests an absence of critical prior events, which is nonsensical in science. Second, the word implies that 1 event is the most important one and as a result, events antecedent to the proximal one are unimportant. Third, the word assumes or implies a linear and sequential order of ecological events, an assumption that is not supported in ecology. Rather, a complex web of events are related to and effect the event that we may be interested in, some more proximal and some more distal than the antecedent event that is usually related to the subsequent effect. Williams (1997) provided a formal view of causality that is helpful, given that our methodology and ability to untangle prior events is limited. He suggested that the term cause can be described as a generic explanation of patterns observed for a class of phenomena and that "causation can be described in terms of antecedent conditions, consequent effects, and a rule of correspondence for their joint co-occurrence" (Williams 1997:1007). Importantly, this definition does not preclude multiple and complex causality. Most ecologists would agree that the nature of ecology is seldom simple. We live in a much more complex world. Most accept the evidence that ecology is complex (Elliott-Graves 2018), multi-causal (Laurance et al. 2007), exhibits unexpected thresholds and non-linear dynamics (Williams 2013), and time lags (du Toit et al. 2016) that may be unpredictable. Further, ecology is mediated by the biological and structural characteristics of the landscape (Bissonette 2003, Froehly et al. 2019) and dependent on the temporal and spatial scales of observation (Bissonette 2013). It is contingent on system history and legacy effects (Ziter et al. 2017) and therefore subject to unpredictable events, suggesting that small changes may bring large system changes, systemic complexity, and complex critical thresholds (Gutswiller et al. 2015). Sells et al. (2018) acknowledge that the H-D approach is a simplification. Given these characteristics, a statement (H-D) approach to wildlife science, although rigorous, may provide but a few reliable pieces of the more complex puzzle and hence, explain only a part of the larger dynamics under study.

NUMBER SYSTEMS: ANOTHER OFTEN-UNAPPRECIATED COMPLEXITY

When wildlife biologists conduct studies, they are usually trying to find answers to interesting questions with management implications. Regardless, the underlying assumption is that there is a relationship to explore. One of the first steps is the selection of the variables to include in a study. However, the complexity of the system in question is always a concern. Not only the number of components involved, but also the nature of their interactions characterize any system, ecological or not. The concept of complexity and science was addressed by Weaver (1948), and number system theory was developed (Weinberg 1975, Weinberg and Weinberg 1979) to help distinguish between the types of possible interactions and to guide the application of appropriate analyses. Three number systems exist (Fig. 1).

Large number systems have a large number of identical components and the interactions expressed as unorganized or random, as in gas diffusion whereby molecules diffuse randomly and are amenable to a simple statistical averaging treatment (e.g., Boyle's Law). Planetary motion describing daily, seasonal and yearly changes has been treated as a small number system with a few components with relatively predictable motions (O'Neill et al. 1986), as have historical ice age climate change dynamics (e.g., the Milankovitch cycles; Hays 1975). The interactions are organized but considered simple and analyzed by a finite, usually small, number of equations. Middle number systems have an intermediate number of components, their interactions are organized, and relationships structured among the components. Ecology is a middle number system (O'Neill et al. 1986).

The Square Law of Computation

So how would we proceed to analyze middle number systems (i.e., problems in ecology)? Here, the square law of computation comes into play (Weinberg 1975) and is where recalcitrant complexity emerges. Solving a problem with n variables, with each variable interacting with the other, takes 2^n units of computation. Five variables would take $2^5 = 32$, 8 variables $2^8 = 256$, and 20 variables $2^{20} = 1{,}048{,}576$ units of computation. Clearly, although we have the computer power to do this, we would hardly be able to interpret the complex results. Hence, when we use strong inference or the H-D method of statement hypotheses with a few variables, we, by default, revert to a small number system approach characterized by mathematical analysis of a subset of variables, with each interaction described by a separate equation. Clearly, there is a mis-match between the number system at which the problem exists and the number system we use to explore the question. At the very least, this should suggest that our conception of rigor equals reliable science is suspect. Things are not so simple.

SIMPLISTIC LANGUAGE?

The language that ecologists use may be inappropriate, too dogmatic, or taken too simplistically. The online Merriam-Webster dictionary gives the following definition of a fact: “something that has actual existence, an actual occurrence, a piece of information presented as having objective reality, the quality of being actual.” (https://www.merriam-webster.com/dictionary/fact). Romesburg (2009:5, 42) argued that quantitative facts were measurements of degree and as such, facts, measurement, and data mean the same thing. To the extent they do, the meaning is clear. Truth in science, however, is never final and what is accepted as a fact today may be modified or even discarded tomorrow.” (https://ncse.com/library-resource/definitions-fact-theory-law-scientific-work, accessed 2/11/2019, 1:08 PM MST). I argue that wildlife biologists might profit by thinking of facts, even if defined as measurement or data, as tentative and probabilistic. It may be prudent to consider a fact as a conjecture or assertion “that has met a certain standard of proof” (Gilbert 2006:184). This is a more nuanced definition and tends to lead to a skeptical empiricist approach. I suggest that the terms truth and facts are often not used rigorously or are misused or misunderstood in science.

Despite the complexities involved in trying to understand the natural world, wildlife biologists still need to try to obtain reliable information. Understanding the nature of the questions addressed (i.e., what, where, when, how, and why) will ultimately influence the most effective study approaches to achieve answers. My primary concern is that we should not fool ourselves into thinking that our results are true or complete, but rather the best we were able to do at that time, given resources available and time allotted. Hypothetical-deductive approaches are necessary, powerful, and useful and if repeated over time and space, can provide generalities that are valuable for wildlife managers. I argue that these concerns argue for skeptical empiricism, coupled with a degree of humility when we assess the results of wildlife studies.

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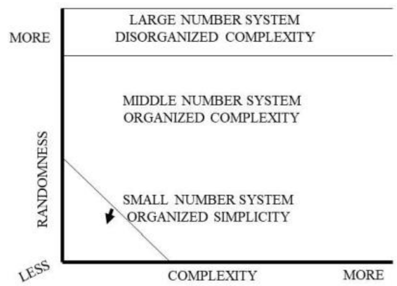
Fig. 1. The relationship between the degree of randomness and complexity in number systems that define areas with different types of interactions that require different approaches to analyses. Adapted from Weinberg (1975). Below are essential characteristics of the 3 number systems. Adapted from O'Neill et al. (1986).

Fig. 1.



Complexity and number systems

Characteristic	Type of number system		
	Small	Medium	Large
Number of components	Few, related, non-identical	Intermediate, related, non-identical	Very large, independent, identical
Interaction type	Simple	Structured relationships	Random
Alternate name	Organized simplicity, linear	Organized complexity, non-linear	Disorganized complexity
Analysis	Math analysis, separate equations, “mechanistic’, square law of computation	Recalcitrant to analysis, a form of the square law of computation, (mechanistic is often used)	Statistical mechanics, averages
Example	Planetary analysis	Ecology	Boyle’s gas laws

Table 1: Construction of logical and illogical arguments. Syllogisms in logic are often confused. Below are shown the logical and illogical forms. Adapted from: Copi and Cohen 2005, and https://www.physics.smu.edu/pseudo/examples_logic.html

These are the 2 consistent logical argument constructions: both are correct logical constructions. Affirming the antecent = Modus Ponens: If A is true, then B is true. A is true. Therefore, B is true. Example: if it is a deer, then it has legs. It is a deer. Therefore, it has legs. Denying the consequent = Modus Tollens: If A is true, then B is true. B is not true. Therefore, A is not true. Example: if it is a deer, then it has legs. It does not have legs. Therefore, it is not a deer.
There are 2 related incorrect and inconsistent constructions: affirming the consequent and denying the antecedent. Affirming the consequent: If A is true, then B is true. B is true. Therefore, A is true. Example: if it is a deer, then it has legs. It has legs. Therefore, it is a deer. So why is this wrong? The thing might have legs but it does not have to be a deer. It could be something else with legs. Denying the antecedent: If A is true, then B is true. A is not true. Therefore, B is not true. Example: if it is a deer, then it has legs. It is not a deer. Therefore, it does not have legs. So why is this wrong? It could be any other thing that has legs.