Environmental Science is Not Laboratory Science: Why This Matters (Newsletter)*

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Karl Popper, considered one of the most influential 20th century philosophers of science defined the scientific method as it is taught in schools, from elementary to post-graduate. The three main steps are:

1) When a science question is asked a testable hypothesis is created for finding an answer. This is called the null hypothesis. The null hypothesis is worded as the negative (false) outcome because hypotheses can only be falsified, not proven true. An alternative hypothesis is created to reflect the expected result.

2) Conduct randomized experiments to test the hypothesis. These need to be replicable so other scientists can do the same experiments and obtain the same (or very similar) results.

3) Analyze the experimental results to determine the truth of the null hypothesis. If the results are greater than a designated probability level (95% by convention) the null hypothesis is accepted; if less than that level the null hypothesis is rejected. A common failing is asserting that rejecting the null hypothesis means the alternative is accepted as the question's answer. This is wrong for many reasons; one is that the alternative hypothesis has not been tested, only the null has been. All we can say about the results is that the null hypothesis has been rejected and we do not have a proven answer to our question.

R.A. Fisher, a British biologist and statistician created the statistical foundation for testing experimental hypotheses in the 1930s. Fisher's approach (called the frequentist paradigm) is based on probability distributions; that is, how frequent a value can be expected to be the result in an experiment when we know the distribution of all possible results. Fisher's approach is also known as hypothesis testing with confidence intervals defining the uncertainty around the experimental value. As an aside, Fisher argued vehemently against assigning a fixed probability of acceptance of statistical analyses of experimental data. He lost that argument which is why almost all null hypothesis tests are rejected when the probability is 0.05 (5%) that the calculated value occurred by chance; that is, rejection of the null hypothesis is correct 95% of the time.

This scientific method is followed (most of the time) in physics, chemistry, and laboratory biology. A requirement of these experiments is that all variables but one are held constant. When this approach is applied to environmental science, especially regulatory science, it produces incorrect answers.

Study of natural ecosystems does not allow scientists to keep all variables constant except for the one of interest. Everything varies all the time, and at different rates. This makes the scientific method and frequentist statistical approach inappropriate for establishing most environmental regulations.

When regulators apply the scientific method to measure effects of cadmium on bull trout a common approach is to put fish (often juveniles) in aquaria (static bioassays) or artificial stream channels (flow-through bioassays) and expose each group of fish to a different concentration of cadmium. These results are then extrapolated to all populations of bull trout. This follows Popper's scientific method of experimenting on the effects of a single variable (cadmium) on the response variable (bull trout). However, it does not represent the real world.

Streams and rivers vary along their length and differ from each other. Rarely is there a single species of fish present so competition and other biotic interactions affect each fish. Habitats, water flow, temperature, and other variables can change daily, seasonally, and annually. Most importantly, fish are exposed to multiple chemicals simultaneously so their reactions reflect their entire biotic and abiotic environment and cannot realistically be isolated to a single constituent.

Environmental science as the basis of laws, statutes, and regulations is an observational science, not an experimental one. This means that data collection and analyses must be appropriate for observations in complex systems where everything is a variable not controlled by man and cause needs to be robustly associated with observations directly and through the interactions of variables. Predictions are more realistic when based on whole ecosystems rather than isolated components.

When done correctly the natural, economic, and social environments benefit. Accepting that environmental and laboratory sciences are different requires applying analytic tools for observational data to reveal the underlying causal properties. The benefits apply to all environmental laws, natural resource industries (agriculture, energy, mining), and lawyers who practice in these areas. Understanding the differences between laboratory and environmental sciences has monetary benefits as well as societal ones for the regulated public, regulators, and natural ecosystems.

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