Appendix 2. Review of scientific terminology.

Basic terms

The design of any research project starts by developing a **research question**, because the value of everything done subsequently depends on its ability to help the researcher address this question. The following is a list of sample research questions:

1. To what extent does technological change ***crowd out behavioral change*** and what balance between technological and behavioral change is appropriate under different circumstances? For example, do recycling efforts lead us to reduce and reuse (the other of the three R's) less?

2. What factors about the current generation in the United States explain why it is ***apathetic*** with respect to particular environmental issues?

3. Can a small-scale biodiesel company that sources its oil primarily from street-food vendors make a profit in a New Delhi neighborhood? If so, what factors would affect the ***financial viability*** of this company?

4. What are the different ***environmental and economic impacts*** of shade-grown vs. sun-grown coffee plantations in Guatemala?

5. Is the cultivation of Jatropha curcas for biofuel production an ***economically advantageous*** option for small-scale farmers in Haiti? If so, what factors enable this outcome?

6. How ***effective*** will a payment for ecosystem services (PES) scheme be in the community of Boca Pariamanu in Madre de Dios, Peru?

7. How can remote sensing and geographic information systems technologies ***lower the transaction costs*** involved in monitoring outcomes of market-based watershed and water quality protection schemes in the Northern Forest region of New England?

8. What is the relationship between the presence of oil refinery sites, fuel-burning plants and ***county-level Medicaid expenditures on asthma***?

9. What makes for an ***effective eco-label*** on clothing?

10. What drives ***tropical deforestation***?

Frequently the formulation of a research question will establish several other elements of a research project. This can include the primary outcome that the researcher wants to explain (such as changes in levels of forest cover). Each of the questions listed above contains an outcome of interest, expressed at various levels of specificity. The terms most closely associated with the outcome to be explained are bolded and italicized in each question. Research questions also frequently imply or establish a **unit of analysis** that exhibits this outcome (e.g. forests) and potentially a particular population of this unit (a set of forests). For example, a researcher could ask, what types of institutional arrangements and property rights regimes help to sustain forest cover? Sustained forest cover is the outcome identified here, and it is an outcome that different forests may exhibit to varying degrees.

Research questions generally inquire about relationships among **concepts**. By "concept" I mean what Adcock and Collier (2001) refer to as a "systematized concept", or one that has been given a fairly specific definition by a particular researcher or research group. Concepts in ESS include both biophysical concepts, such as "forest cover change" as just described, and social concepts, such as "resource dependence" or the extent to which a user group depends on a natural resource. Many social concepts are very intangible and difficult to measure with much precision. **Variables** are like concepts but are assigned a well-defined range along which they can vary (such as high, medium, or low). Variables are essentially what we turn concepts into in order to measure them. The process of turning a concept into a variable is called **operationalization.**

Statements that describe (1) a causal relationship between two or more concepts, and (2) the mechanism by which this occurs are called **theories**. Theories are generally derived from **induction**, or the process of forming generalizations based on patterns found in a set of observations. Several authors (Young 2002; Cox 2008) have argued that the most desirable theories in ESS are **mid-range theories**. These are theories that are not so specific that they are overfit to, or only relevant for, a particular case or dataset, but also are not so general as to be broadly but only superficially applicable to many types of cases. One example of a mid-range theory is what Berkes et al. (2006) refer to as "roving banditry." This describes the tendency of highly mobile resource users to serially deplete a set of resources when they are not dependent on any particular one of them. It has been mostly discussed in the context of fisheries management, due to the highly mobile nature of the resource and the consequent mobility of many fishing actors.

Next, a **hypothesis** is sometimes used to refer to a theory for which there is little evidentiary support. I prefer to use the term to refer to the observable patterns we would expect to find in our data if a theory were true. Essentially a hypothesis as an observational implication of a theory. Ideally we can unpack multiple observational implications of a particular theory so that we can test the theory in multiple ways via a process known as **deduction**. Many texts describe deduction and induction as being entirely distinct steps of the scientific process, occurring iteratively or in a sequence. But in practice they frequently occur at the same time: deductive hypothesis testing via statistical analysis may find unexpected patterns in the data, and the process of data collection, even when it is not explicitly guided by a set of hypotheses, is frequently "theory-laden."

Variables also are found in **frameworks** and **models**. Ostrom (2005) has discussed the difference between these, as well as their relationship to theories, at length. She states: "Frameworks…provide the most general set of variables that should be used to analyze all types of settings relevant for the framework. Frameworks…attempt to identify the universal elements that any relevant theory would need to include." More briefly, Schlager (2007, 294) states that the primary goal of a scientific framework is to "provide theories with the general classes of variables that are necessary to explain phenomena."

A scientific framework is a way of organizing the phenomena under investigation into broad categories, subdividing a rather continuous world into discrete chunks in order to analyze the relationships among these chunks. For example, in ecology, scientists frequently make a basic distinction between autotrophs and heterotrophs to organize their analyses. For institutional economists, concepts such as transaction costs, incentives, information, and rationality are equally important as a way of organizing their view of the world (see Ostrom 2005). In some cases frameworks are formalized and presented in a cohesive package in a particular published work. Indeed, there are many formal frameworks in the ESS literature, including Ostrom's (2007) diagnostic social-ecological framework and the Robustness framework (Anderies et al. 2004). Binder

et al. (2013) recently presented a summary and comparison of numerous social-ecological frameworks.

Models in ESS are similar to theories, but are more precisely formalized. A model is essentially a set of one or more (frequently mathematically) formalized theoretical statements, each of which is related to the others to describe how a system works. Within ESS, agent-based models have become quite popular in the last several years (see Parker et al. 2003; Janssen and Ostrom 2006). In some fields, notably both economics and ecology, the term "theory" ("theoretical ecology" or "economic theory") actually refers to the practice of formalizing theories through the art of mathematical modeling (May and McLean 2007).

Next, we have **units of analysis** and **units of observation**, which are two terms that are easily confused. A unit of analysis for a research project is the category or unit about which the researcher is trying to answer questions. A research question presented at the beginning of a paper will often explicitly mention, or ask a question about, such a unit. Common units of analysis in ESS include individuals, households and communities which are involved in environmental management (Ostrom 1990; Agrawal 2001), and/or affected by large-scale environmental change (Osbahr et al. 2010; Cinner et al. 2012), as well as larger-scale environmental policies, governance systems, and their associated ecological jurisdictions (Keskitalo et al. 2009; Augerot and Smith 2010).

We don't actually examine a unit of analysis in a research project. Rather we study instances of a unit of analysis, or **observations**, and the unit of analysis is the category to which these observations each belong**.** For example, we might want to understand outcomes for a set of trees in a forest. If so, the category of "tree" is our main unit of analysis, and we will probably try to compare different individual trees to look for patterns across these trees. There are two types of such comparisons that can be made: **cross-sectional comparisons** and **longitudinal comparisons.** In a cross-sectional comparison, the observations are different entities (e.g. trees) at the same point in time. In a longitudinal comparison, we compare the same entity at multiple points in time, say each year. So in this case our observations wouldn't be different trees, but different years for one particular tree. If we have panel data, which involves multiple observations of each entity over time, we can conduct both types of comparisons at once. Here our observations would be tree-years.

While a unit of analysis is what we analyze and observations are what we compare, a unit of observation is what we observe. They may well be the same thing as a unit of analysis: we might directly observe trees in order to collect the data needed to compare them. But the two don't have to be the same thing. In order to infer the value of variables describing our observations, we may rely on multiple data sources, or units of observation. For example, if we are trying to compare towns, we probably won't directly observe them, but instead may rely on key informant interviews with town citizens about them. Here the town is the unit of analysis, but we "observe" key individuals who provide us with information about the towns. Additionally, a unit of observation should not be confused with a method of observation. There are multiple ways in which we might try to observe a tree or a forest (e.g. directly with our eyes or through remotely sensed images).

Types of relationships among variables

A defining characteristic of ESS is the emphasis on multiple types of relationships among variables. Figure A2.1 demonstrates several of these graphically. Each graph in this figure shows a relationship between several variables by plotting a hypothetical set of observations along two dimensions, X and Y. We are usually concerned with finding patterns of **covariation** between variables, in which a

change in one variable causes a change in another variable. Each variable in such a relationship can be thought of as a cause, or **independent variable** (IV), or an effect, or a **dependent variable** (DV). Variables per se are not dependent or independent, but may be used in a given analysis in one or both ways: as outcomes to be explained, or as factors that affect outcomes. Or, if the research is purely descriptive and not causal, they can be thought of as neither.

An IV can covary positively or negatively with a DV. A **positive relationship** (Figure A2.1 A) means that an increase in the IV causes the DV to increase as well (slope is positive), and a **negative relationship** (Figure A2.1 B) indicates that an increase in the IV causes a decrease in the DV (slope is negative). If this slope is relatively constant over the range of both variables, then the relationship is **linear** (A2.1 A and A2.1 1B are both roughly linear). If the slope of the relationship between two variables changes at some threshold, say going from positive to negative, then the relationship is **nonlinear** (Figure A2.1 C). The nature of a relationship frequently changes fundamentally as a threshold is crossed.

One source of non-linearity is **endogeneity**, which describes a situation in which a supposed DV in fact causes an IV to change. This may simply be reverse causality, where the supposed IV does not affect the DV, or it may be a case in which two variables are mutually affected by each other, either in a negative relationship, which produces **negative feedback**, or in a positive relationship, which produces positive, self-reinforcing **positive feedback**.

Positive feedbacks, as a source of nonlinearity, are particularly important to recognize, as they create the conditions for a range of behaviors in social and ecological systems, including resilience, path dependence, technological lock-in, and hysteresis (Gunderson and Holling 2002). Each term here broadly reflects the tendency of systems to self-reinforce themselves along a particular social or ecological path, sometimes in spite of a shift in the efforts of decision-makers in those systems. For example, Scheffer et al. (2001) describe a shift from grasslands to deserts that has occurred in many parts of the world. Once grass species disappear, the conditions that had facilitated their persistence, which they themselves enabled, disappear as well. So a desert-like condition may persist, even if human actors remove the initial cause of the transformation (say by removing livestock that had grazed on the grass).

Related to nonlinearity are the concepts of **necessity** and **sufficiency**. These can be understood via the following logical arguments:

If X is necessary for Y, then:
(1) If X is absent, then Y must be absent
(2) If Y is present, then X must be present

If X is sufficient for Y, then:
(1) If Y is absent, then X must be absent
(2) If X is present, then Y must be present

One simple example of necessity in ecology comes from Leibig's of the minimum, which plays a prominent role in agricultural science, and states that plant growth is constrained by the most limited nutrient, implying a necessity of each of a set of nutrients, and a lack of fungibility among them. Some have argued that the roles of distinct institutional arrangements and processes (e.g. property rights, monitoring and enforcement) on environmental and development outcomes are similarly necessary and non-fungible (Kirsten 2009). Within the ESS literature, these concepts are most

closely related with the method of qualitative comparative analysis as promoted by Charles Ragin (1987, 2000), which will be discussed later.

In addition to assuming linearity, scientists frequently simplify their view of the world by thinking primarily of **independent effects**, or the effects that an IV has on a DV, irrespective of changes in any other variables. In contrast, an **interaction effect**, as shown in figure 1 and figure A2.1 D, occurs when two or more IVs interact to affect a DV. This occurs when a **moderator variable** affects the nature or magnitude of the relationship between an IV and a DV. For example, the effects of acid rain on soils depend in large part on the buffering capacity of those soils: the more buffering capacity there is, the less acidic the soil is made by a given amount of rain. In figure A2.1 D, variables Z is the moderator variable that affects the relationship between variables X and Y. Interaction effects are the reason why the most responsible answer to an environmental policy question is usually "it depends." The role of research in this context is to unpack the ways in which "it depends" in a generalizable way, to produce mid-range theories.

A similar, but distinct, phenomenon occurs when the effects of an IV on a DV are mediated by a **mediator variable**. This is also shown in figure 1. For example, in a Dominican fishing community I have worked in, we found that members of the local fishing association tended to catch certain types of fish, and these types were significantly different from non-members. They also fished much closer to shore than non-members. What we ultimately found, however, is that this effect was mediated by the fact that members fished without compressors, and the use of fishing technology played the dominant large role in determining where they fished and what fish they caught. Gear type served as a mediating variable in this case.

The process of mediation in turn relates to the distinction between **proximate causes** and **underlying causes** or drivers, which has been used extensively in the literature on land use and land cover change. A proximate cause is most directly connected to an outcome of interest. An underlying cause is what explains or produces the proximate cause. Underlying drivers affect outcomes via a proximate, mediating variable. Geist and Lambin (2002), for example, identify a mix of political and economic underlying causes of agricultural expansion, which is in turn an important proximate cause of deforestation in many countries. This distinction is basically a way of tracing back a path of processes that lead to an outcome. Underlying causes frequently change more slowly, and are more difficult to change, than are proximate causes. But it can be difficult to change an outcome of interest by proximate causes alone. A related distinction made by many researchers is between slow variables and fast variables, with slow variables, such as soil properties (e.g. phosphorous content) serving as a context for more quickly-moving variables, such as crop production. Walker et al. (2012) comment that fast-moving variables are more frequently the objects of management, just as proximate causes are more easily governed.

Figure A2.1: Types of variable relationships