3
Some teaser problems

To illustrate some of the ways that we can employ a deliberate problem solving process, apply general heuristics, and look toward development of solution strategies, I offer some teaser problems. We'll revisit these problems throughout the text where they serve as fodder for more targeted discussions of solution strategies. These problems vary in complexity and are in most cases fairly open-ended. As we've already discussed, these are features of real problems and though we may feel a bit of anxiety about that, we should also realize that this presents *opportunities* for creativity and ingenuity.

3.1 Waterfowl easements

To have the greatest benefit to migratory waterfowl, is it better secure easements containing many small wetlands or fewer, larger wetlands?

One of the greatest threats to waterfowl populations is loss of habitat. Organizations like Ducks Unlimited and The Nature Conservancy have advocated for preservation and restoration of wetlands in key migration corridors and breeding areas. Among the strategies that organizations like this have used is acquisition of conservation easements, wherein a private land owner agrees to limit development on land containing quality habitat in exchange for benefits like management assistance and tax deductions. In practice, these organizations cannot accept all easement donations but need to prioritize those that will have the greatest long-term benefits to waterfowl. Thus the question: if all else is equal, is it better to prioritize a parcel with many small wetlands, or a parcel of the same size with fewer, large wetlands (Figure 3.1)?

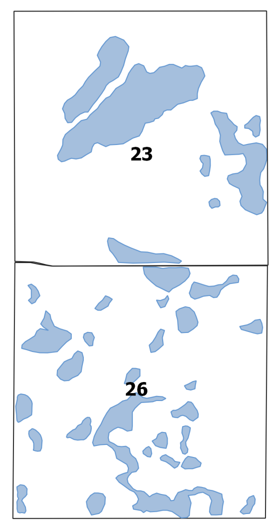

Figure 3.1: Two adjacent sections, each approximately 1 square mile, with different number and size distribution of wetlands.

3.2 Herbicide purchase

How much herbicide is needed to kill and suppress regrowth of invasive woody shrubs in a wooded urban park?

A common management problem in urban woodlands is the control of invasive or unwanted understory vegetation. In the midwestern USA, bush honeysuckles (genus *Lonicera*) and European buckthorn (genus *Rhamnus*) are particularly challenging to manage, and the most effective means of control is usually with herbicide. The simplest approach for many of these woody invasives is to cut all the stems and paint stumps with a general herbicide like glyphosate. So what must we know and determine to decide upon the quantity of glyphosate required?

3.3 Deer-automobile collisions

How likely are collisions between automobiles and whitetail deer in your county, and how might they be influenced by changes in deer population management?

If you live in an urban environment without open spaces and wildlife corridors, the answer to this may be easy: zero likelihood. But in many areas both periurban and rural, deer are a familiar sight. In these settings, deer-automobile collisions may unfortunately be all too common. We might infer that the frequency of collisions would be greater where both deer and drivers are more numerous, but can we quantify this?

3.4 Prairie dog plague

Is it possible to prevent the spread of Sylvatic plague through prairie dog colonies?

Yersinia pestis is a flea-borne bacterium that causes Sylvatic plague, an often fatal disease that primarily affects rodents. The black-tailed prairie dog (*Cynomys ludivicianus*), already threatened by land-use change and hunting/poisoning within it's native range in the North American Great Plains, periodically experiences plague epidemics that can decimate colonies. In addition to harming prairie dogs directly, however, plague can be transmitted both directly and through fleas from prairie dogs to their predators, including the endangered black-footed ferret. In isolated populations of prairie dogs, monitoring and active management can potentially be used to reduce the spread of plague, but designing such a strategy requires that we first understand the dynamics of disease transmission within colonies.

3.5 Forest fire losses

How much fuel management is optimal to minimize risk of fire damage in a forest managed for timber production?

In many western forests managed for timber production, historical fire exclusion has led to a buildup of fuel wood, leading to heightened risk of destructive fire. When fires do occur in these settings, high fuel density can lead to destructive crown fires that greatly diminish the value of the timber and can damage or destroy surrounding infrastructure. To combat this, forest managers can undertake fuel reduction treatments such as thinning and prescribed burning, and emergency managers can aggressively fight fires when they do start. However, such suppression and pre-suppression efforts can be costly and can have diminishing returns in terms of cost and resources (Figure 3.2). Is there an optimal amount of fuel reduction and suppression that provides some protection from risk while containing costs?

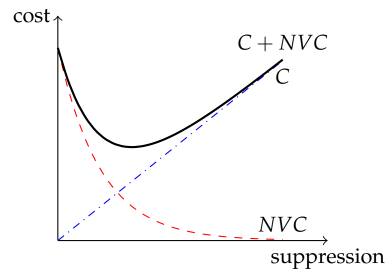

Figure 3.2: Schematic illustration of one conceptual model for the optimal management of fire fuels. Total cost C of management increases with suppression and pre-suppression effort. With little suppression effort however, the risk of high losses or net change in value, NVC, is high, declining with suppression effort. This view of management incentives indicates that overall cost is $C + NVC$.

3.6 Maximized effluent

How much of phosphorus (P) can be discharged from point sources into an urban stream without exceeding total maximum daily loads (TMDLs)?[1]

[1] Inspired by Litwack et al., 2006, *Journal of Environmental Engineering*, 132(4): 538-546.

The U.S. Clean Water Act of 1972 establishes criteria for identifying polluted water bodies and designing plans to reduce pollutant loads and improve water quality. One of the measures available to water resource managers is the establishment of Total Maximum Daily Loads (TMDLs), which typically limit the permissible concentration of a pollutant in an impaired water body. If the goal in this case is to limit the amount of P delivered to downstream water bodies, we need to determine how much P constitutes the maximum allowable concentration.

3.7 Brook trout recruitment

Given data from four consecutive electrofishing passes in an isolated stream reach, what is the stream's age-0 brook trout population?

One method of estimating fish populations in streams is to isolate a stream reach with barriers upstream and downstream of and performing an electrofishing transit of the reach, collecting and measuring each fish retrieved. When extra detail is needed or fish are elusive, multiple passes through the reach may be required, and retrieved fish are removed to a live well or adjacent reach. Through this method, the change in catch between consecutive passes can be used to estimate the actual population within the reach. To isolate the population of age-0 (young of the year) fish, age must be assessed from each fish either directly[2] or indirectly from the length distributions in the catch in each pass.

[2] A nonlethal age estimate can be obtained by collecting and observing fish scales under a microscope

THE PROBLEMS ABOVE deal with a variety of practical issues that could be addressed by a natural resource professional. None of them are expressed explicitly as math problems, but quantitative methods could be instrumental in solving each of them. Indeed, this is characteristic of many real science and management problems. Before they become quantitative problems, they must be interpreted and carefully re-framed (Figure 3.3). This is not only an important part of the process, but in many cases is the most challenging and pivotal step. In practice, this must be part of the process of understanding the problem and perhaps even planning a solution strategy. In most cases, not enough information is given up front and the expectations for the kind of solution desired are vague. In this sense, they are ill-structured problems, requiring some digestion and careful re-phrasing before they can be understood as solvable quantitative problems.

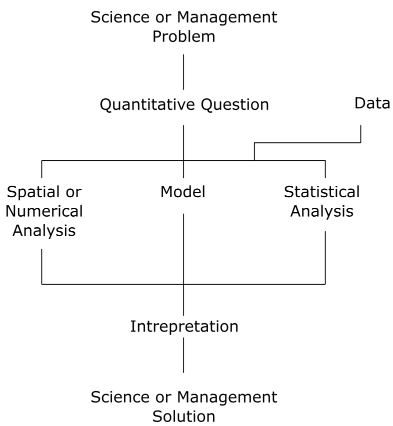

Figure 3.3: A pathway between problems and solutions in practical natural resource management, including various quantitative approaches.

Gathering the information deemed necessary to arrive at the solution is, of course, an essential step in the process. When possible, we should strive to include this step as part of the coursework. However the design of experiments and logistics of making novel field measurements can and should be addressed in their own courses, and we cannot hope to do justice to those concerns here. As a consequence, where the teaser problems are addressed here and in the chapters that follow, we'll either work with hypothetical data or engage real data from the literature or from government documents and web resources.

Importantly, these problems also vary in the degree to which we could ever hope to know that we have the "right" answer. For example, It may indeed be possible to know exactly the maximum P load delivered in Problem 3.6 or the herbicide volume needed in Problem 3.2, provided that we had perfect information on stream discharge and stem basal area, respectively. However, for most of the other problems, confidence that we have a good solution must come from confidence that we have made well-reasoned interpretations and assumptions and used technically-correct manipulations and analysis. Thus, part of the burden of solving such a problem is articulating how the problem is interpreted and how chosen solution strategy follows from that interpretation.

Each of these problems provides hints or implicit cues to what kinds of strategies are appropriate to assemble a solution. For example, there are clear spatial elements to Problem 3.1 and Problem 3.2, but there may also be subtler spatial components in others. By spatial, I mean that we need to incorporate information about how big or how long something is into our solution. Addressing these elements of problems requires some tools from geometry and trigonometry, as well as perhaps the language and conventions of geography or cartography. Therefore, this book contains several chapters exploring the aspects of spatial reasoning that arise frequently in natural resources.

Spatial reasoning is the use of spatial information or relationships, like lengths, areas, volumes, or directions, in the solution of problems.

Not surprisingly, several of these problems point to issues of *how many*, particularly Problem 3.3 and Problem 3.7. In these and other problems, we may wish to characterize individuals or populations in terms of a representative value or distribution of values, or we may need to compare values or proportions. These tasks engage our experience with arithmetic, descriptive statistics, and probability, but in many cases also require that we are careful with units and that we can work efficiently with the extremely large or small numbers sometimes encountered in the sciences. For these issues, we have several chapters devoted to numerical reasoning.

Numerical reasoning, as used in this book, is the manipulation, characterization, comparison, and interpretation of numerical values (such as data) in the service of problem solving.

Aspects of most of our problems can be expressed in terms of the relationship between multiple variables, or relationships between cause and effect. For example, in Problem 3.5 we may need a way to represent the relationship between how much effort is made in fire-suppression activities and their cost. Since we don't necessarily have an idea ahead of time about how much effort is appropriate, an algebraic expression relating the variable C (cost of suppression efforts) to the amount of suppression effort itself (call it S) could stand in and allow us to employ algebraic reasoning as a means to a solution.

Algebraic reasoning is the use of generalized variables and formal relationships between them, rather than numbers, as a means of constraining solutions.

Finally, several of these problems imply that we seek an assessment or prediction of future, hypothetical, or unobservable quantities or events. For example, Problem 3.4 seems to ask whether something is even possible, even though we don't know what that something is. In these cases, finding a useful solution may require modeling. As indicated in Chapter 1, a model is simplified representation of real systems and is constructed for the purpose of exploring cause and effect or functional relationships between variables as system conditions are changed. To model the spread of plague among prairie dogs, then, we may need a way to characterize the transfer of fleas between an infected individual and an uninfected, but susceptible individual. This type of reasoning will often require algebraic constructs and simplifying assumptions, and may therefore require competency in algebraic reasoning. Even so, however, some insights can be gained from model construction even if the detailed relationships between

Modeling in this book refers to the construction of a simplified representation of real or hypothesized systems, often described with one or more equations relating variables to one another and to system properties, and used to explore complex or unobservable phenomena or relationships.

variables aren't formally articulated with equations.

The Parts and Chapters that follow are elaborations and demonstrations of problem-solving strategies employing each of these types of reasoning. Not all will be applicable to every problem, and there isn't necessarily a sequence of interdependence. Therefore, I hope that rather than reading the text in order, that you will consult it as the need for ideas and insight arises in problems you are presented with. I don't provide complete solutions to any of the teaser problems above, but do use parts of them to illustrate concepts and strategies as they arise.

Exercises

1. Which of the teaser problems outlined above do you find most interesting or compelling and why?
2. Using the table on solving ill-structured problems in Chapter 2 as a guide, attempt to UNDERSTAND a teaser problem of your choice from the list above. Write your response to each of the questions under the UNDERSTAND prompt, or write "n/a" if not applicable.
3. Try to write one or part of one of the teaser problems as a more conventional math problem, with only equations and no words. What is challenging about doing this?
4. Write a problem of your own in a format similar to the teaser problems above: a short title, a boldface question, and a short paragraph elaborating on the context or significance of the question. Choose a natural resource topic that interests you.