Part I

Introduction, Dynamic Systems, and Change

1
Introduction

1.1 Resources, Environment, and People

This book is about resources viewed in the context of their environment and people. It is not an economics, policy, or business text; instead, it gives the status and trajectory of the environment and resources so that better informed economic, business, and other policies can be made. Resources will be discussed in five categories: water, agriculture, energy, minerals, and forests. Three categories of the environment will be discussed: climate, landforms, and biodiversity. The general model for this book is depicted in Figure 1.1.

Figure 1.1 has the shortcomings of all models. It is a simplification of the underlying network structure. It appears here as a hierarchy to emphasize that upper levels are initially formed by lower levels. Once formed, both upper and lower levels can influence each other, even to the point of annihilation; consequently, the system transforms to a network [1]. These concepts will be discussed in Chapter 2.

People will be discussed separately, since they are both a resource and part of the environment [2, 3]. Their capabilities as manual or intellectual labor and problem solvers, and their creativity, place them as a major resource. But they are also a significant factor in changing the environment in all three categories discussed.

"Raw materials" are unaltered physical components used by people. People commonly modify raw materials into small and large tools and infrastructures (axes, looms, roads, bridges) known as "building blocks" (Chapter 2). The concept of building blocks can be expanded to include intangible skills and institutions as well as tangible entities developed from raw materials.

Exactly what constitutes a resource is somewhat arbitrary, but resources will be considered here as tangible entities that people use to survive and prosper. Discussions of intangible intellectual property, economics, policy, pure ideas, and technologies are beyond the scope of this book.

The use of raw materials and building blocks change over time and space; therefore, the demand for a resource – and what is considered a resource – changes. For example, copper for telephone wires was a widely used resource but is being replaced by photo-optics and then by wireless cell phones.

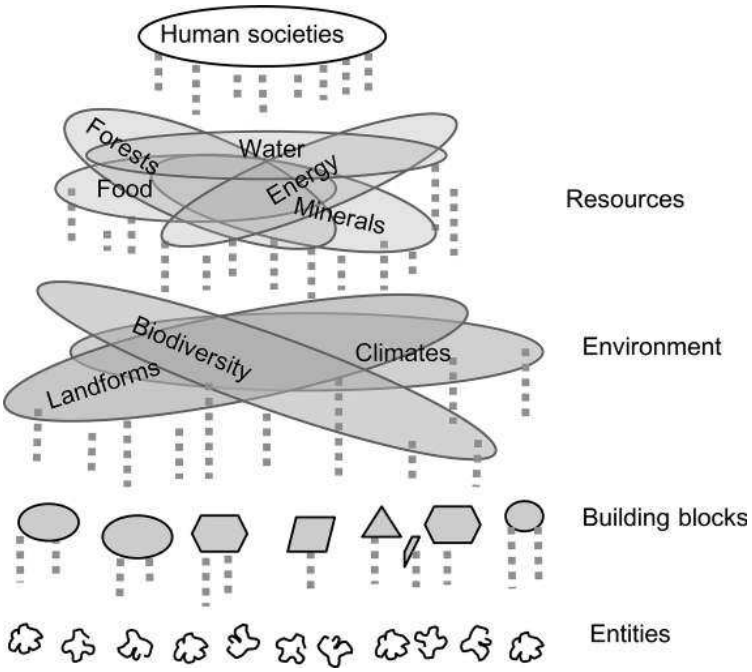

Figure 1.1 General model discussed in this book. (A black and white version of this figure will appear in some formats. For the color version, please refer to the plate section. Color plate 1.)

The human population more than doubled from 3 to 7.3 billion people from 1960 to 2015, and is expected to exceed 9 billion people by 2050 (Figure 5.11). The urban environment is expected to triple by 2050 to 9% of the Earth's land surface [4], possibly at the expense of forests. Farmland may increase slightly, both with population growth and with more people demanding a protein-rich meat diet. The desert areas at low latitudes will probably expand with global warming, but the upper latitudes will probably not warm enough to make the current boreal, tundra, and polar lands more habitable.

There are optimistic and pessimistic trends. The agriculture area has remained nearly stable since 1960 (Figure 21.5), and people are receiving more food (Figure 22.10) despite a doubling of the world's population (Figure 5.11). The world fertility rate halved from 5.0 to 2.5 births per female between 1960 and 2015 (Figure 5.8). The effects of the fertility decline will be felt during the next few decades. If the trend continues, the population may soon stabilize and even decline to a less precarious level.

1.2 Focus of the Book

The book's focus is detailed discussions of each resource with respect to properties, availability, global distribution, and management. Extensive use of currently available data supports these discussions. The attempt is to provide an in-depth understanding of

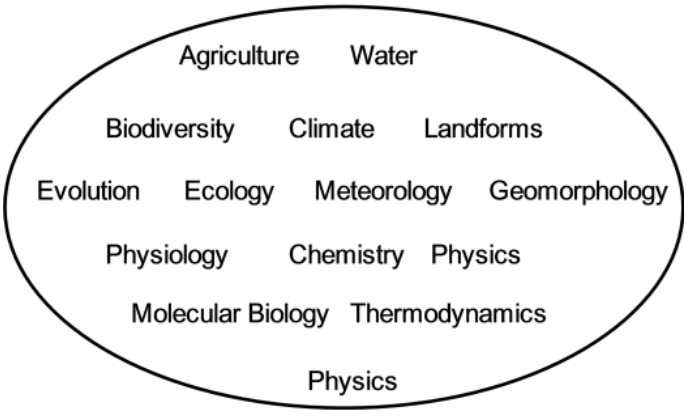

Figure 1.2 A conceptual hierarchy of scientific disciplines from more fundamental (bottom) to more applied [9].

each resource and the environment. As more data become available the graphs and the charts can be updated. Interactions and changes over time and scale, human-induced or otherwise, will be emphasized.

The challenge will be to keep the present and impending large numbers of people from damaging the environment and resources that sustain them – and thus dramatically constraining themselves.

Resource management is an art and a science. The need is to anticipate and manage change so that the human species and those aspects of the environment and resources vital for its survival are maintained – most notably, clean air, clean water, food, and biodiversity. The other very important issue is to promote equity – inter- and intra-generational rights to productive lives for all people [5, 6]. Quick, short-sighted, emotional fixes are to be avoided at all costs.

The book is optimistic. It stands midway between environmental ruin and technological heaven [7]. Although depletion and misuse generate very serious challenges, the world currently has sufficient food, energy, water, and minerals; an abundance of wood; and biodiversity can be stabilized [8]. Despite heartbreaking violence in several places, the pace of advancement in renewable resources shows people can overcome challenges. Optimism is not only warranted, but necessary to give people the confidence to undertake the changes that are needed for everyone to have.

Changes in climate and many other features always have occurred and always will. Scientists now have at least some understanding of how these changes might take place and how dire ones can be adapted to.

Each field of learning exists within a hierarchy of disciplines (Figure 1.2), with physics as the most fundamental discipline. Other fields (disciplines) emerge from fundamental principles as one ascends in the hierarchy. Fundamental fields are used to "explain" or "understand" the behavior of fields immediately above [9]. For

example, understanding of climates and biodiversity helps the understanding of agriculture; understanding of evolution and ecology helps the understanding of biodiversity; understanding of physiology helps the understanding of evolution and ecology; and so on. Theoretically, a learned person would be able to comprehend all resources by understanding physics – and even comprehend economics and human behavior. In practice, an expert in each field tries to maintain a strong awareness of fields immediately above and below their specialty, so they can understand how new information can be incorporated.

1.3 Recurrent Themes

Several recurrent themes emerged as the book was being written.

"Social drivers" will mean new behaviors, ideas, institutions, or employment that form the core of a larger population's varying lifestyle [10, 11]. Social drivers will be discussed throughout this book.

Small, resource-based cities constructed in rural areas could offer relief from overly crowded large cities. Their core employment could be scientifically and technically knowledgeable people using new, small-scale, technical tools to manage farms and forests in place of costly large machinery and broad-scale uniform practices. Local secondary manufacture would add another source of labor. As small cities, a threshold population would exist to provide amenities that attract secondary employment in services and entertainment that would make people not want to migrate to large cities.

1.4 Socioenvironmental Systems

Systems are groups of interrelated entities of any kind, with several characteristics:

- The properties or behavior of each subgroup of the group affects the properties or behavior of the whole group;
- The properties and behavior of each subgroup depend on the properties and behavior of at least one other subgroup;
- The properties and behavior of each subgroup are affected by the properties and behavior of the whole group;
- The way that one subgroup affects the whole group depends on the properties and behavior of at least one other subgroup.

Every possible subgroup of a system has all four characteristics. Each has an effect and none can have an independent effect on the whole system; consequently, subgroups cannot be treated independently. A system has some properties or behaviors that none of its subgroups has. This behavior is referred to as "emergence." The system loses these properties and behaviors when it is taken apart. The subgroups of a system may themselves be systems, and every system may be a subgroup of a larger system (Chapter 2) [12, 13].

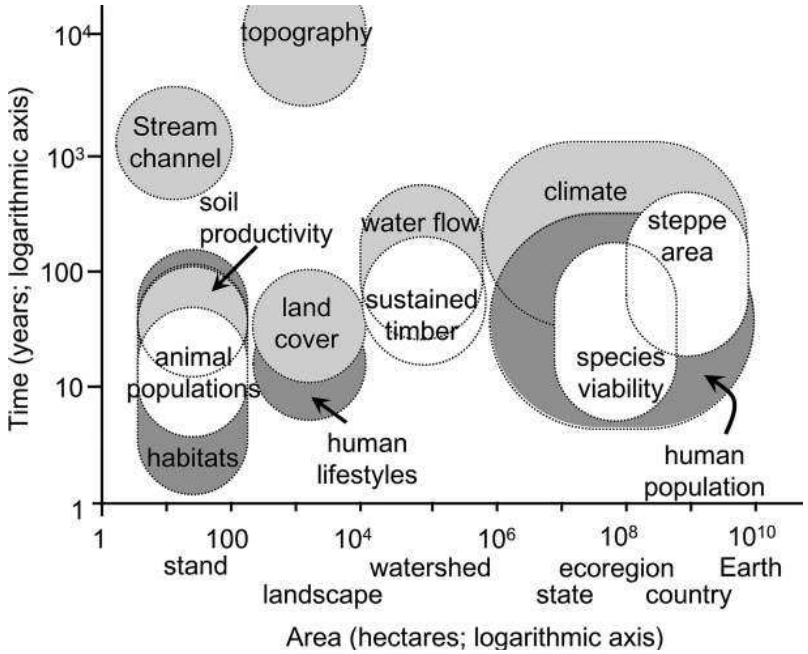

Figure 1.3 Different spatial scales and rates of change for some properties of resources and the environment [19, 20]. Reproduced with permission of Taylor and Francis Group.

Social, economic, ecological, and environmental systems interact so closely that it is appropriate to address "socioenvironmental" systems rather than distinct "human" and "natural" systems [14–18]. This recognition is appropriate because nearly all of the world is influenced by – and influences – people. However, combining human and environmental systems is a dramatic change in our embedded way of thinking. It means that "natural" has little meaning and cannot be used as a baseline "ideal" against which to measure human impact. Avoiding human impact is not a sure way of preventing harm to the environment. Socioenvironmental systems are complex (Chapter 2).

Each resource, the environment, and people are continuously changing because of innate processes, external disturbances, and human needs. They change at different rates and scales, and a wide variety of conditions can materialize at the various times and spaces (Figure 1.3) [20]. Together, these changes can hinder the return of the socioenvironmental systems to a previous condition, even if this return were desirable.

1.5 Spatial and Temporal Scales

Resources exist at a variety of spatial scales (Figure 1.3). We address resources from very small scales, such as the individual fruit, mineral, or person, to intermediate scales, such as

the landscape or ecosystem to the entire Earth [20]. People have broadened the scale of where they obtain resources. Presently, many resources are transported worldwide.

The rise of complex societies has been attributed to the need to coordinate resources across larger areas [21]. The early trade of resources over large areas has become more prevalent as transportation and communication have become rapid and inexpensive.

This global sharing of resources has allowed many more people to live more comfortably than they otherwise could. People travel farther and more regularly and are increasingly linked into an international network of connections that make communication very rapid – from accessing immediate business-oriented information, to sharing creative ideas and health remedies, to connecting with distant friends. People rarely die of some common diseases that once were fatal.

Problems have also arisen with expansion to the global level, including moving plants and animals to foreign areas where they become pests; exploiting resources in one region to profit people in another; pollution from one region spreading to others; and bad investment decisions in one region causing economic problems in another.

People and resources are not uniformly distributed in the world, nor are concentrations of people matched with concentrations of needed resources; however, people have a strong ability to sustain themselves based on what is available.

Both the distributions and changes of people and resources have patterns – some more obvious than others. Analyses of global inventory data over the past decades are helping elucidate the patterns.

The 180+ world countries are commonly grouped by regions ("country groups") of similar resources, cultures, and environments to facilitate understanding of the patterns. The United Nations uses 22 country groups; however, this book further divides some United Nations groups and uses 32 country groups (Figure 1.4).

1.6 Organization of the Book

The book is divided into eleven parts of one to four chapters each. An introductory section sets the stage by describing complex systems and their implications for sustainability and change. The second part discusses human societies and people's abilities to adapt, make choices, cooperate, and so form and sustain themselves. Human societies are perhaps the most complex systems.

Then, sequential sections discuss the three environmental factors of climates, landforms, and biodiversity, followed by five parts on resources: water, agriculture, energy, minerals, and forests. The organizations of the sections vary. Generally, each section first describes the properties and distribution of its subject. Then, it discusses how its subject changes and can be managed. During these discussions, the effect of each subject on the other resources, environmental aspects, and people is expounded. The last section considers an overall perspective and the integration of all resources.

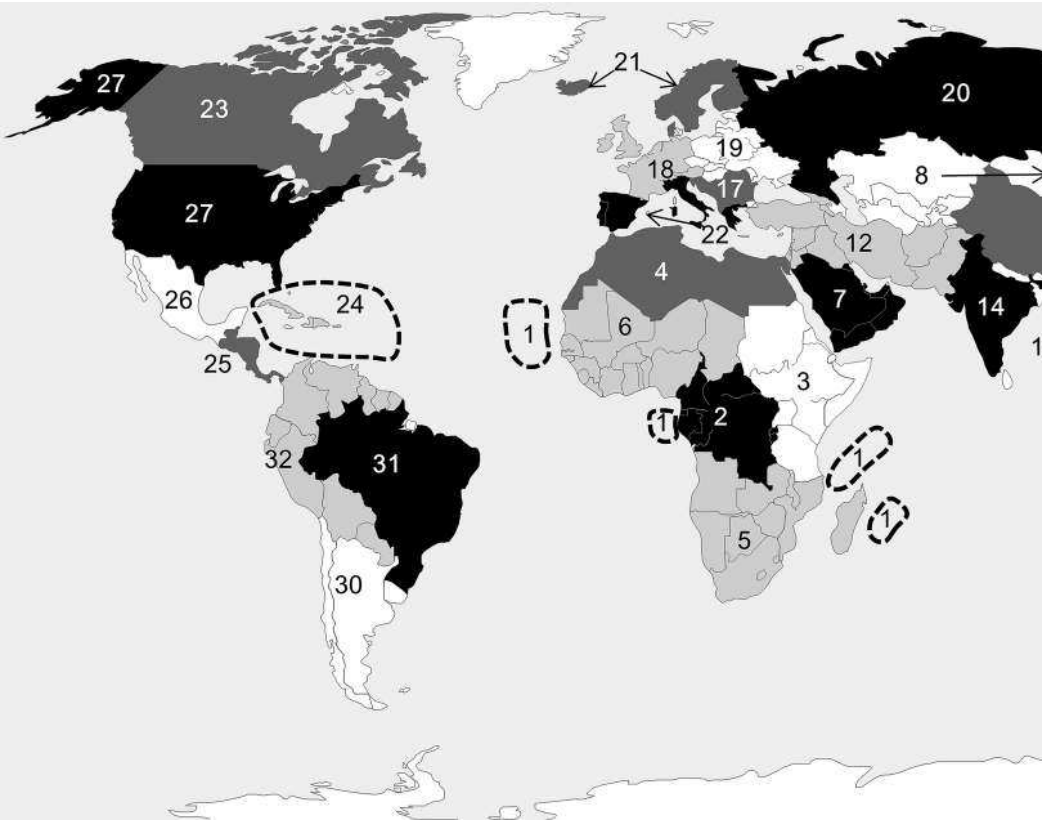

Figure 1.4 The 32 country groups referred to in this book. See Appendix I for countries in each group.

Near the ends of most sections are suggestions for possible actions that could be taken, with their merits and shortcomings. Some actions may be mutually exclusive, and some will be easier to implement than others. These suggestions were developed by the authors, by students at the School of Forestry and Environmental Studies and the Jackson Institute of Global Affairs at Yale University, and by others. It is hoped that the suggestions will stimulate readers to develop creative ways to manage the environment and resources.

The book incorporates maps, graphs, and statistical analyses and makes use of recently emerging large data sets. It also discusses trade-off issues [22].

References

1. Y. Bar-Yam. General Features of Complex Systems. *Encyclopedia of Life Support Systems (EOLSS)*. (UNESCO, EOLSS Publishers, 2002).
2. J. L. Simon. *The Ultimate Resource 2*. (Princeton University Press, 1998).
3. A. Goudie. *The Human Impact on the Natural Environment*, sixth ed. (Blackwell, 2006).
4. K. C. Seto, B. Güneralp, L. R. Hutyra. Global Forecasts of Urban Expansion to 2030 and Direct Impacts on Biodiversity and Carbon Pools. *Proceedings of the National Academy of Sciences*. 2012;109(40):16083–8.
5. C. D. Oliver. Sustainable Forestry: What Is It? How Do We Achieve It? *Journal of Forestry*. 2003;101(5):8–14.
6. G. Brundtland, M. Khalid, S. Agnelli, et al. *Our Common Future*. (Oxford University Press, 1987).
7. Y. N. Harari. *Sapiens: A Brief History of Humankind*. (Random House, 2014).
8. E. Von Weizsacker, K. Hargroves, M. Smith, C. Desha, P. Stasinopoulos. *Factor Five: Transforming the Global Economy through 80% Improvements in Resource Productivity*. (Earthscan/Routledge, 2009).
9. C. D. Oliver, B. C. Larson. *Forest Stand Dynamics*, update ed. (John Wiley, 1996).
10. G. Björklund, R. Connor, A. Goujon, et al. Chapter 2. Demographic, Economic and Social Drivers, in *The UN World Water Development Report 3: Water in a Changing World*. (UNESCO, Earthscan, 2009): pp. 29–40.
11. E. Dugarova, P. Utting. *Emerging Issues: The Social Drivers of Sustainable Development*. (UN Research Institute for Social Drivers, 2013).
12. R. L. Ackoff. Science in the Systems Age: Beyond IE, OR, and MS. *Operations Research*. 1973;21(3):661–7.
13. D. Meadows. *Thinking in Systems: A Primer*. (Chelsea Green Publishing, 2008).
14. F. Berkes, C. Folke. *Linking Social and Ecological Systems*. (Cambridge University Press, 1998).
15. J. Liu, T. Dietz, S. R. Carpenter, et al. Coupled Human and Natural Systems. *AMBIO: A Journal of the Human Environment*. 2007;36(8):639–49.
16. P. Matson, W. C. Clark, K. Andersson. *Pursuing Sustainability: A Guide to the Science and Practice*. (Princeton University Press, 2016).
17. M. Cote, A. J. Nightingale. Resilience Thinking Meets Social Theory: Situating Social Change in Socio-Ecological Systems (SES) Research. *Progress in Human Geography*. 2012;36(4): 475–89.
18. A. Hornborg. Introduction: Conceptualizing Socioecological Systems. In: C. Crumley, ed. *The World System and the Earth System: Global Socioenvironmental Change and Sustainability since the Neolithic*. (Left Coast Press Inc., 2007): pp. 1–11.
19. C. S. Holling. Understanding the Complexity of Economic, Ecological, and Social Systems. *Ecosystems*. 2001;4(5):390–405.

20. C. D. Oliver. Functional Restoration of Social-Forestry Systems across Spatial and Temporal Scales. *Journal of Sustainable Forestry*. 2014;33(Supplement 1):S123–S48.
21. J. Tainter. *The Collapse of Complex Societies*. (Cambridge University Press, 1990).
22. C. Oliver, M. Twery. Decision Support Systems/Models and Analyses. In *Ecological Stewardship: A Common Reference for Ecological Management*. (Elsevier, 1999): pp. 661–85.