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ABSTRACT

Biogeography examines questions of organism inventory and pattern, organisms' interactions with the environment, and the processes that create and change inventory, pattern, and interactions. This learning module uses time series maps and simple simulation models to illustrate how human actions alter biological productivity patterns at local and global scales. The module also demonstrates how human alterations of land cover change the dispersal processes that affect the distribution patterns and diversity of organisms. It aims to engage students actively in problem solving, challenge them to think critically, invite them to participate in the process of scientific inquiry, and involve them in cooperative learning. The module is appropriate for use in any introductory and intermediate undergraduate course that focuses on human-environment relationships; it includes more student activities and more suggested readings than most instructors will have time to cover in their courses, so instructors will need to select those readings and activities best suited to the local teaching conditions. Each section of the module presents background information for the specific topic, the instructor's guide to activities, student worksheets, and answers to activities. A glossary of terms, supporting materials, and readings conclude the module. (Contains 17 references.) (BT)

HANDS-ON!

Living in the Biosphere: Production, Pattern, Population, and Diversity

An Active Learning Module on the Human Dimensions of Global Change

HANDS-ON!

DEVELOPING ACTIVE
LEARNING MODULES ON THE
HUMAN DIMENSIONS OF GLOBAL CHANGE

Living in the Biosphere: Production, Pattern, Population, and Diversity

Module developed for the AAG/CCG2 Project
"Developing Active Learning Modules on the Human Dimensions of Global Change"

by

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Editor's Note

A major goal of this project "Developing Active Learning Modules on the Human Dimensions of Global Change," is to disseminate instructional materials that actively engage students in problem solving, challenge them to think critically, invite students to participate in the process of scientific inquiry, and involve them in cooperative learning. The materials are appropriate for use in any introductory and intermediate undergraduate course that focuses on human-environment relationships.

We have designed this module so that instructors can adapt it to a wide range of student abilities and institutional settings. Because the module includes more student activities and more suggested readings than most instructors will have time to cover in their courses, instructors will need to select those readings and activities best suited to the local teaching conditions.

Many people in addition to the principle author have contributed to the development of this module. In addition to the project staff at Clark University, the participants in the 1995 summer workshop helped to make these materials accessible to students and faculty in a variety of settings. Their important contributions are recognized on the title page. This module is the result of a truly collaborative process, one that we hope will enable the widespread use of these materials in diverse undergraduate classrooms. We have already incorporated the feedback we have received from the instructors and students who have used this module, and we intend to continue revising and updating the materials.

I invite you to become part of this collaborative venture by sending your comments, reactions, and suggested revisions to us at Clark. To communicate with other instructors using hands-on modules, we invite you to join the Hands-on listserve we have established. We look forward to hearing from you and hope that you will enjoy using this module.

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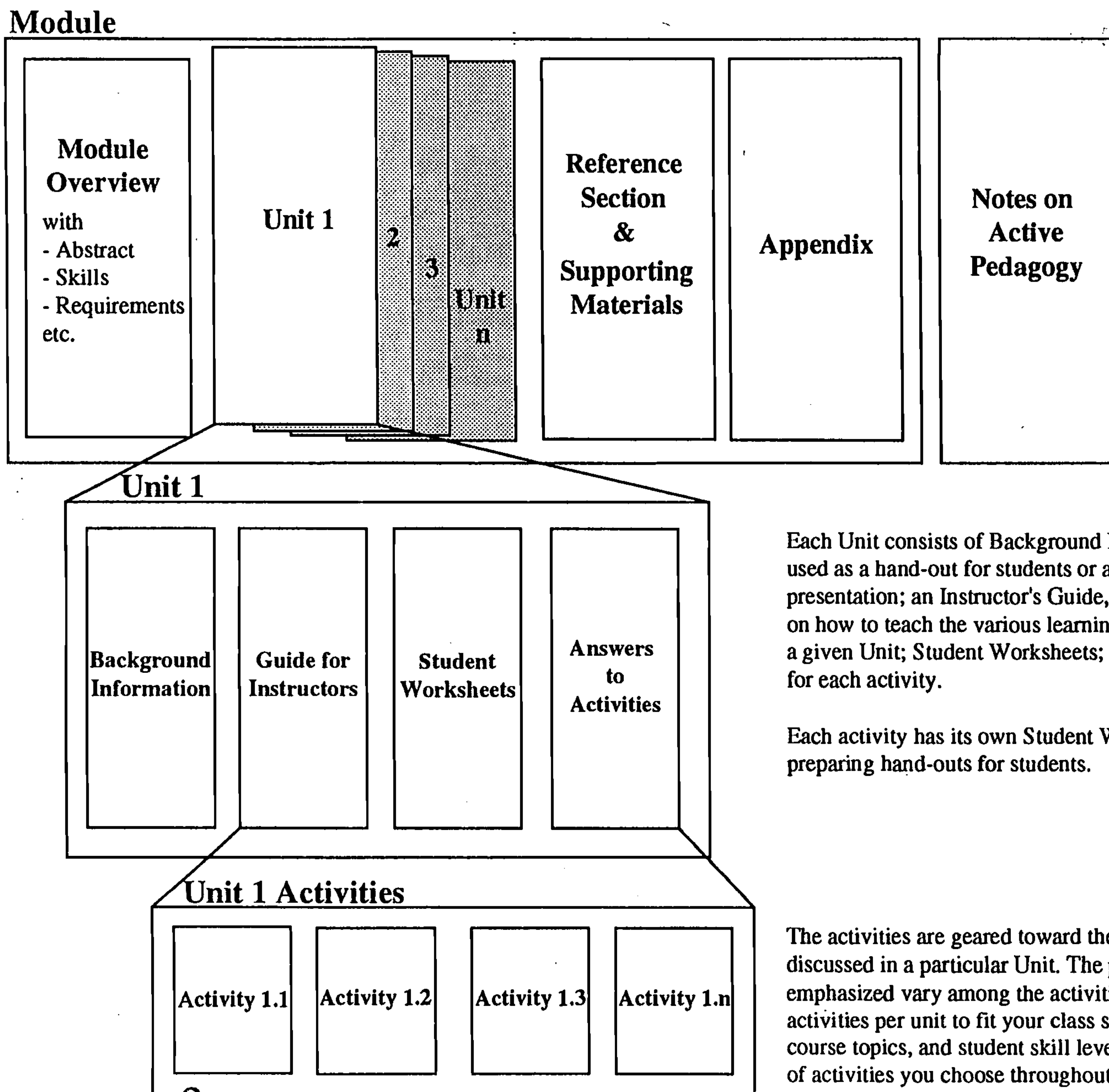
List of Acronyms

AAG	Association of American Geographers
CCG2	Second Commission on College Geography (within the AAG)
GCC	Global climate change
GEC	Global environmental change
HDGC	Human dimensions of global change

Guide to this Module

This guide is meant to help you navigate this module.



The module is divided into Units, i.e., sections that are thematically coherent and that could, if necessary, stand alone. In addition, the module contains a Reference Section, Supporting Materials and an Appendix. The Supporting Materials can be used to facilitate the teaching of this module or simply to augment it with interesting ideas and information. Additional sections with further information may or may not be present, e.g., a list of accronyms, or a glossary. A separate section on Active Pedagogy comes with every module purchase.

Each Unit consists of Background Information that can be used as a hand-out for students or as the basis for an in-class presentation; an Instructor's Guide, consisting of suggestions on how to teach the various learning activities associated with a given Unit; Student Worksheets; and the Answers expected for each activity.

Each activity has its own Student Worksheet for ease of preparing hand-outs for students.

The activities are geared toward the theme(s) and concepts discussed in a particular Unit. The particular skills and themes emphasized vary among the activities. Choose one or more activities per unit to fit your class size, time, resources, overall course topics, and student skill levels. Be sure to vary the types of activities you choose throughout the module.

Summary: Living in the Biosphere: Production, Pattern, Population, and Diversity

Abstract

Biogeography examines questions of organism inventory and pattern, organisms' interactions with the environment, and the processes that create and change inventory, pattern, and interactions. What organisms are present in the assemblage of a space is an inventory question. The productivity of that space is a question of the environmental interactions of the organisms there. The question of an organism's distribution in differing abundance is a pattern problem. This module uses time series maps and simple simulation models to illustrate how human actions alter biological productivity patterns at local and global scales. The module also demonstrates how human alterations of land cover change the dispersal processes that affect the distribution patterns and diversity of organisms.

Module Objectives

Students will develop an understanding of

✓ the differences among major terrestrial biomes;

✓ the concepts of nutrient mass budgets, food web linkages and efficiencies, and organism dispersal processes;

✓ the impacts of climate, land cover, and resource management changes on the inventory, functioning, and patterns of biological organisms;

✓ human and non-human intrusions in nutrient transfers in the food web and organism dispersal;

✓ the advantages and limits of simulation modeling as a way of knowing.

Skills

The module builds the following skills:

✓ interpreting flow charts;

✓ understanding of the distribution of world climates and soils;

✓ analyzing and interpreting maps;

✓ using spreadsheet software to simulate spatial differences in nutrient budgets of the biosphere;

✓ performing geographical analysis of spatial patterns of organisms;

✓ analyzing simple sensitivity experiments of human intrusions into the environment;

✓ empathizing with other organisms and other cultures.

Activities

The activities in this module include:

✓ detecting personal links to distant biomes

✓ modeling nutrient cycling and human intrusions in the food web in a spreadsheet;

✓ detection of geographic patterns and their underlying processes, using maps and other types of information;

✓ graphic analysis of modeling experiments of human intrusions in the dispersal process.

Human Dimensions of Global Change Concepts

✓ human alteration of biological processes

✓ biodiversity

✓ land use and land cover change

Geographical Concepts

✓ geographic scales (local to global)

✓ (changes in) pattern and diversity as results of processes

✓ space, context, and distance

✓ Spatial differences in environmental characteristics
✓ nature-society relations

Time Requirements

✓ 4 class days (assuming that all units are used and one or two activities per unit are completed)

Material Requirements

✓ Student Worksheets (provided)
✓ Windows-based spreadsheet like Quattro Pro 5.0 or Excel
✓ Animator Player Program (provided)
✓ Africanized Honey Bee animated map sequence (provided)
✓ Glacial animated map sequence (provided)
✓ Grass migration animated map sequence (provided)
✓ Tree migration animated map sequence (provided)
✓ *NUTCY4* spreadsheet model (provided)
✓ *DIVERSE3* spreadsheet model (provided)
✓ Pencils
✓ Paper
✓ Readings (some are provided)

Difficulty

Moderately challenging. The module requires some basic conceptual understanding of ecology and geography, and uses a spreadsheet, but does not ask students to undertake complicated modeling. The challenge lies in depicting and establishing connections between processes and patterns, as well as between human actions and local-to-global environmental change.

Module Overview

How do the biological resources of a place respond to proximate human activities such as cutting trees, building cities, or cultivating fields and to more distant human actions and decisions such as the pricing of hamburger or the enactment of laws affecting land and resource use? Human activity can transform the environment by enhancing, halting, or modifying environmental processes; humans also react to those transformations by adapting to changed environments. In short, humans interfere with various energy flows and mass transfers and thereby alter local-to-global nutrient flows and the distribution patterns, diversity, and abundance of species.

This module examines the links between (1) the human dimensions of global environmental change (including causes, impacts, and responses), and (2) biogeographic patterns and dynamics. The focus is on the scale at which each of the processes occur, ranging from the molecular or submolecular level for abiotic processes to the global scale for disturbance and dispersal processes. The module focuses on how changes in a process at particular geographic scales affect biological production, pattern, population, and diversity of organisms. The material in this module also treats ecology explicitly in its spatial context, i.e., it includes the exchanges of mass, energy, and genetic materials across boundaries and scales. Boundary conditions are recognized as dynamic, and exchanges with environs depend on the attributes of the surrounding spaces in all directions.

This module focuses on four fundamental areas of biogeography that are linked to environmental variability and change:

- the **mass transfer** processes that work through the hydrologic, carbon, and nutrient cycles;
- the importance of populations of organisms at various positions in the **food web** in recycling nutrient energy;
- the processes by which organism **populations occupy space**; and
- the roles played by **disturbance** and **dispersal** in assembling sets of diverse organisms in geographic spaces.

The goal is for students to become familiar with the concepts of nutrient mass budgets, food web linkages and efficiencies, and organism dispersal processes as a basis for studying the impacts of climate, land cover, and resource management changes on the inventory, functioning, and patterns of biological organisms. In the module activities, students use maps, simulation models, and other means to relate human actions to changes in the biotic environment.

Overview of Module Activities

The activities in this module are designed to teach some basic concepts, problems, and methods of Human Dimensions of Global Change (HDGC) research. In addition, students learn some fundamental learning, communication, and research techniques.

A variety of activities is offered in each unit. You should select those activities that are feasible for your class, according to class size, students' abilities, institutional facilities and resources, etc.

Organizational Note

The activities section in each unit has three parts: an *Instructor's Guide*, *Student Worksheets*, and an *Answers* section (again for the instructor). For example, Unit 1 is accompanied by Activities 1.1 through 1.5. The *Instructor's Guide* for this unit outlines suggested readings, material requirements, the skills taught in each activity, learning outcomes, and a detailed description of the tasks students have to complete and how to teach the suggested activities with possible alternatives and variations. The *Student Worksheets* (one per activity) are meant as hand-outs to students; they provide the necessary instructions for each activity. The *Answers* section lists expected results of each activity, i.e., either specific results or points to look for in students' answers. See the *Guide to this Module* for an overview of how the individual parts of this module fit together and could be used.

1 Introduction to Biogeography and the Human Dimensions of Global Change

Background Information

Introduction

When you first picked up this text and read the title "*Living in the Biosphere: Production, Pattern Population, and Diversity*," did you wonder what this "biology topic" had to do with geography, let alone with the **human dimensions of global change**?[1] If you did, you just asked yourself one of the most relevant and interesting questions in global change research! This first unit tries to explain why geographers are interested in processes occurring in the biosphere. What are they looking at when they speak of the "human dimensions of global change?" and in what ways do the biospheric studies overlap with, or contribute to, the study of the human dimensions of global change? The answers to these three questions will provide the framework for this module.

What is the Biosphere? What is Biogeography?

Let us begin with clarifying what is meant by the term biosphere before we get into the questions posed above. The biosphere is the totality of all regions of the earth that support ecological systems, or more simply put: all those regions on the planet that support and are affected by life. The biosphere is made up of parts of the atmosphere (air), the hydrosphere (the realm of water), and the lithosphere (the solid portions of the earth, rocks).

So, "Why are geographers interested in the processes occurring in the biosphere?" First of all, not all geographers are. There are really two kinds of geographers that are interested in the biosphere, one more directly than the other. The members of the first group would call themselves "biogeographers" because they look at the biosphere through geographical "glasses." We'll come back to that below. The other group, which is more broadly and more loosely defined, is made up of those geographers whose work falls into the nature-society tradition within geography. These geographers study not the biosphere per se, but the two-way interactions between humans and

[1] Terms that appear in **bold** within the text are also defined in the glossary.

their environment. We will come back to this as well when we look at the human dimensions of global change.

If we had to draw lines delineating the subject areas of biologists, ecologists, and biogeographers, they would be rather blurry ones. You can think of it as dividing up the "biosphere cake" among these three (and maybe some others), yet once in a while one of them would grab a bite from the other one's plate. Biogeographers share with biologists and ecologists the effort to compile inventories of organisms; biogeographers share with ecologists in particular the search for understanding the interactions among organisms and between organisms and their environments, even though biogeographers probably focus more on the latter type of interaction. And biogeographers, perhaps more than the other two, are interested in the distribution of organisms. What distinguishes biogeographers from biologists and ecologists is their propensity to look at inventory, interactions, and spatial distributions at different geographic scales. Biologists and ecologists focus more on the population, organism, and suborganismic levels, whereas biogeographers usually start at the population level and go to the global scale. One could argue that biogeographers must move from one scale to another if their overarching goal is to understand why species occur, in the way they do, where they do.

The Human Dimensions of Global Change

Global change is probably not a new phrase for you. For years now, people have been speaking about global climate change and global warming -- to name but two common examples. But "global change" really means something much broader than what these two examples indicate. The term refers to changes in the environment more generally. Oh yes, you might say, I have heard of some others: deforestation, desertification, soil erosion, loss of biodiversity, acid rain, ozone depletion (another climate example). All of these are excellent examples of global environmental changes. And yet, the term is even broader.

The examples given so far all imply human interference with the natural environment. This is one important dimension of global change, and it is what we will be concerned with later on in this module. Yet it is essential to understand -- not only in order to place the human dimensions of global change into the larger global change agenda, but also to understand some of the difficulties and controversies in global change research -- that global changes can be entirely "natural," i.e., they can occur without the interference of humans. Examples of entirely natural changes are climate changes stemming from variation in the intensity of sunlight that we receive; geologic events or processes with global impacts, such as major volcanic eruptions or continental drift; and species extinction as a result of such solar/climatic and/or geologic processes. Global changes are usually the combined result of "natural" and human causes, and often we don't know to what extent change is due to one or the other.

For most of the 1970s and 1980s, global change research (even if it acknowledged or assumed human causality) focused on the physical dynamics of global change. Since the mid-

1980s social scientists have highlighted the need for research on what they call the human dimensions of global change. There are three basic human dimensions, each one of which, when unwrapped so to speak, has many additional facets and components to it:

- the **causes** or **driving forces** of global change:
  - ❑ natural causes versus societal causes
  - ❑ large underlying societal forces (macro forces) versus proximate sources of change in any particular case

- the **impacts** of global environmental change on society (or regions and sectors of it):
  - ❑ vulnerability versus resilience in the face of changes (which determine the extent of impacts
  - ❑ interactions, synergisms, and complexity of impacts in various world regions, economic sectors, and social groups of society

- the **responses** of society to these changes and impacts:
  - ❑ e.g., differential vulnerability and ability to respond of various populations
  - ❑ questions of early versus late adaptation to changes in the environment

This brief overview of the human dimensions of global change suggests why geographers can make considerable contributions in this area: the questions researchers ask about the human dimensions of global change deal -- in one way or another -- with the interactions between humans and their environment .

How Does Biogeography Relate to Human Dimensions of Global Change Research?

Thus far, we have unquestioningly accepted the common perspective that distinguishes between a natural world and a human(-made) world. We maintain this general distinction throughout the module, yet we should be aware that some scientists don't draw such a sharp line between the two. For example, from an ecological and/or biogeographical perspective, humans may be viewed as just another species. There is no unanimous agreement whether one of these perspectives is better suited than the other to understanding the dynamics and implications of global change. More likely, each perspective has its merits for some of the questions, but not for others. You might want to think about this for yourself.

We forgo this discussion and instead focus on how biogeographic research relates to research in the human dimensions of global change. If we create a mental overlay of the previous two sections, we can see that biogeography contributes to our understanding of the human dimensions of global change and vice versa in several ways.

Biogeography, as mentioned earlier, attempts to understand the factors that contribute, and the processes that lead, to the variability in geographic distribution patterns of ecosystems and populations of organisms, the variability in productivity and biodiversity at various scales, and to variations in reproductive patterns. The factors and processes may be entirely natural, or (as is more likely the case today) they may be influenced by human interactions with the environment.[2] Biogeography thus contributes to our understanding of the causes of global change in tackling the difficult task of separating human from non-human influences. It also contributes to our understanding of the impacts of global change in grappling with concepts like the fragility, sensitivity, and resilience of different kinds of ecosystems in the face of disturbance. Biogeography also attempts to establish qualitative and quantitative causal linkages between human interference (driving forces) on the one hand, and changes in the natural environment (changes and impacts) on the other. This is an enormously important area of research as both the human and the natural world are extremely complex and interconnected in many ways that are often invisible or intangible. Research on the links between driving forces and environmental change must consider feedback loops between human actions and ecosystem response and vice versa.

Another important aspect is that biogeographers as well as global change researchers work at various scales: from the local to the global. Although we speak of "global changes," we need to remain mindful of the fact that the actual processes that lead to change occur locally and then either accumulate to cause change that is global in scope (cumulative change) or fundamentally change the spheres of the earth (such as the atmosphere, the biosphere, etc.) systematically (systemic change). In fact, the module focuses mostly on what will be called here the "process scale," that level at which the actual changes in the biosphere occur.

A final area in which global change research overlaps with biogeographic research is in the methods each uses. Both engage in field studies, in historical analyses of biogeographical changes in response to human interference (e.g., through the investigation of geologic records), and -- of increasing importance -- in simulations (in particular, computer-based modeling) of "what-if" situations, i.e., of possible future states of the natural environment.

In this module, we cannot deal with all these areas of overlap, which include themes, scales, and methodology. Instead, this module will focus on the following:

Main themes: productivity at various scales;
natural variability in the geographic distribution patterns of biomes;
biodiversity at various scales
Secondary themes: qualitative and quantitative (causal) linkage between human interference and changes in the natural environment
Methodology: simulation (computer modeling) of what-if/future situations

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[2] Indeed, some researchers maintain that no corner on earth remains untouched by humans. What distinguishes environments really is the degree to which humans *manage* them.

Scale: biome >> ecosystem >> species >> individual organism (process level) >> and back to the biome level.

The remainder of the module is divided thematically into units on production, patterns, and diversity. The secondary theme of human-environment interactions and scale issues resonates throughout these units. In the activities associated with the units, we will -- among other things -- actually try some simulations. But first, let's turn to some basic concepts of ecology and of doing research, so that we understand the technical terms used in later units and better see how the units relate to each other.

Some Basic Concepts of Ecology and Science

Ecology is the science of the mutual interactions between organisms and their environments, and of interactions among organisms. These interactions are enormously complex and the aspect of mutual interdependence is highly important. Organisms don't just "make do" with their environments, whatever they find in terms of rocks, soil, water, light, temperature, precipitation, etc. Organisms also alter their environment to suit their needs.

The **geographic distribution** (or **patterns**) of species result from many factors. Changing one factor, e.g., the mean temperature, as is expected with global climate change, may not necessarily lead to a radical alteration of these patterns. How sensitive a species is to changes in single factors again depends on a variety of factors. Patterns are controlled by more factors than just climate. Similarly, **production** is the result of complex interactions and factors. Temperature and water availability, two climate-related factors, may be crucial for a certain species and in other cases may not be a so-called **limiting factor**. Because we do not yet know exactly how the global climate will change in the future, or how different species will respond to these environmental changes, predictions of production levels of any species are fraught with difficulties and uncertainties.

It is generally easier to look at the relationship between a species and just one or two environmental factors than to take all or even just a few relevant factors into account (e.g., soil conditions, other species competing for the same environmental resources, mobility, adaptability of a species). You will have the opportunity in some of the activities of this module to observe how patterns and production levels change over time as you change just one or two environmental factors, even though things are more complex in reality.

Before we can simulate species behavior in a computer model, we need some data to base our calculations on. Where do these data come from? Data are the result of **observations**. Our way of knowing about species or resources and how they interact with each other and the environment begins with observation. Observations are simply what our senses tell us about our surroundings (Gersmehl and Brown 1992). Ways in which we observe in this broad sense include thermal sensing (the sunshine on my shoulders feels warm); tactual sensing (touching) of a weed, e.g., velvet leaf (*Abutilon theophrasti*), telling us that the leaf is soft; visual sensing (and interpreting) that the leaf looks smooth. Other senses include hearing and tasting.

As we sense, we compare objects with each other as a way of recognizing and organizing information. A common tool for organizing information is classifying the observed objects into groups with similar characteristics. Classification into groups is a mental construct. These classes do not exist as such in nature; their purpose is to simplify our analysis by organizing information. These groups or units are found here and there, but not somewhere else. An observation that a unit once was there but is no longer is a fundamental observation of space and time. We develop ways of organizing "where" and "when" by using spatial coordinate systems and time scales, both of which must have communicated reference bases if they are to be used to transfer information.

Observation, in order to be informative, must:
- ❑ examine the level at which the process takes place;
- ❑ view the whole subject (Saxe 1882);
- ❑ record the subject at time intervals consistent with its rates of change; and
- ❑ recognize the contexts of the process as it progresses.

As a matter of convenience, we commonly use artificial constructs to simplify the way we look at organisms. The concept of a **species** (a group of similar organisms that can produce viable offspring, and a term that classifies individual organisms in a simplifying manner) is basic to most of the biology of whole organisms. We must recognize that this is a mental construct, created by humans. All classifications have advantages (see above), but they also have the disadvantage of filtering information and thereby modifying and limiting what we learn from the original observations. For example, the construct of species classification may distill information from observations, but it may also obscure our view of the relationships between species or of evolutionary processes at work.

When we look at **populations** of organisms and **mixings** (the cause of diversity), we focus on the level or scale of individual members of that population and the processes occurring among them. Alternatively, when we try to understand organism production processes, we work at the molecular level. Occasionally, we view biological processes at scales different from the ones where they really occur. As a result, we may find inconsistent observations at different scales, or we may make claims about linkages between organisms and their environments that are not entirely appropriate. For example, we may see a correspondence (correlation) between a population or the range limits of certain organisms and various environmental traits. These correspondences are not necessarily causal. In other words, the distribution of an organism need not depend on features of the space in which it exists.

An example of this is the range of certain birch and pine trees. From observation we learn that certain birch and pine species are common in bogs and on the edges of swamps and wetlands. We conclude from this obvious correlation that the natural range of these tree species is delimited by the extent of bogs and wetlands, when in fact their range is theoretically much broader, i.e., they could exist in other types of environments as well, but because of competition from other tree species that fare better in non-swamp environments, the effective range of these birch and pine species is limited to areas where they have a competitive advantage, i.e., in bogs and on the edges of wetlands.

In order to avoid this mismatch between the scale at which we observe something and the scale at which the process of interest really happens, we will use theories here that work at the process level, and we will choose organisms from a larger population of organisms (a process called **sampling**) in a way that will recognize the factors at work at a particular scale. To do so we use a **sampling design** that defines the spatial and temporal distance between taking samples. Sampling designs that dictate either too wide or too narrow a spacing of observations are not useful for describing a pattern, nor are they capable of detecting a change in pattern. Transect A in Figure 1 below shows observations at 100-kilometer intervals across the forest (F) and prairie (P) border. If observation 6 were at the western edge of the forest, and the next observation point were 100 kilometers to the west into the prairie or to the east into the forest, we would gain absolutely no information about how the edge of a forest gradually changes to open land (prairie) or to forest proper. This distance would, however, be sufficient to determine where about the prairie-forest line was located (see transect A below). In transect B, the distance between observations is 200 kilometers. Water (W) is located between some observation points, but it is missed because the spatial resolution of the sampling design is not fine enough to capture this land cover feature.

Figure 1: Transects across the forest/prairie border at different observation intervals

Transect A

	West									East
Observation Pt.	1	2	3	4	5	6	7	8	9	10
(100 km distance between points)	P	P	P	P	P	P	F	F	F	F

Transect B

	West									East
Observation Pt.		1		2		3		4		5
(200 km distance between points)		P	W	P	W	P	P	F	W	F

Legend:

P -- prairie
F -- forest
W -- water

Source: by author

The following units examine the issues of biological production, geographic pattern, and organism diversity in more detail. These features of the biosphere are related and must in the end be seen together because pattern and diversity affect production and vice versa.

1 Introduction to Biogeography and the Human Dimensions of Global Change

Instructor's Guide to Activities

Goal
The goal of the activities associated with Unit 1 is to help students place themselves in the biosphere and help them recognize how closely dependent on, and tightly interwoven with, the natural environment humans really are. Even though a perception of this interdependence is hindered by our apparent removal from the natural environment through life style, location, technology, and culture, the dependence on natural resources and the impacts on the natural environment are present nonetheless. They are epitomized in the human causation of global change and in the impacts of global environmental change on society.

Learning Outcomes
After completing the activities associated with this unit, students should be able to:

- determine their place in the biosphere (geographically, ecologically), using maps and other information sources
- display and present biogeographic information creatively and understandably
- work in teams
- understand and critically discuss the content of a film
- think relationally (connect bits of information to identify a biome; see human-environment relations)

Choice of Activities
It is neither necessary nor feasible in most cases to complete all activities in a unit. Instead, select at least two or more from each unit, covering a range of activity types, skills, genres of reading materials, writing assignments, and other activity outcomes. For this unit, the following activities are offered (note that not every activity is accompanied by a *Student Worksheet*):

1.1 Which biome are you in?	-- relating items to biomes (in-class)
1.2 What's this got to do with me?	-- determining biomes and envt'l impacts of land use
1.3 Film "Preserving our Global Environment"	-- film-viewing and discussion; reaction paper (optional)

1.4 Field trip	-- field observation and report
1.5 Writing a biome biography/drawing a biome profile	-- out-of-class project and presentation of results in class

Suggested Readings

The following readings are recommended to accompany the activities for this unit. Choose those readings most appropriate for the activities you select and those most adequate for the skill level of your students. A hand-out on how to take good notes from readings is provided in the *Supporting Materials* section. We recommend strongly that students use this hand-out and make note-taking a permanent habit.

- Unit 1, *Background Information* (provided)
- any additional selection at the instructor's discretion on biogeography (textbook) or the relationship between biogeography and global change (see the *Supporting Materials* section for an annotated bibliography of such texts)
- any topical newspaper article illustrating the linkages between the biosphere and global changes

Activity 1.1 Which biome are you in?

Goal

The goal of this activity is for students to realize how they as individuals are linked to biomes; it also links their daily lives to the scientific concepts introduced in this first unit. The activity thus serves well as a short class opener.

Skills

✔ creative and relational thinking
✔ oral presentation

Material Requirements

Student Worksheet 1.1 (provided)
items representing biomes (supplied by students, and instructors)
(Large world map of biomes to display in class)

Time Requirements

In-class: 15 minutes

Task
Before you do this activity, ask each student the next time they come to class to bring in something from home that illustrates something about a biome of their choice. In a small class, students can show items individually; in larger classes, divide the students into biome groups. You may ask students to tell in a few sentences how their item relates to the biome and how they personally use the item. For example, a student may bring in a potted cactus to represent the desert biome and may say the plant is well adapted to store water against dry conditions. For the student the cactus may be a collector's item, a decoration, or a hobby.

Encourage students to be creative and to search their homes for the most interesting article(s). This may range from bananas and other fruits, to nuts, to rubber goods, to fur items, to plush animals, etc. A safety reminder is in order should students bring in live pets. One of the module contributors had the experience of a student bringing in his live boa constrictor in a duffle bag!

You may want to have a world map of biomes in your classroom to help students locate the biomes that are represented by their items. This will begin to build students' geographic knowledge of biomes and make them realize how they are linked to distant regions.

Activity 1.2 What's this got to do with me?

Goal
This activity is a variation on Activity 1.1 in which students also recognize the connections they have with various (some quite distant) biomes. Students identify biomes through a number of items representing them. The activity can be used as a starting point for a class discussion on sustainable use of different biomes.

Skills
✔ relational thinking (detecting links between items)
✔ critical awareness

Material Requirements
"Biome trash bags" (put together by the instructor)
Student Worksheet 1.2 (provided)

Time Requirements
In-class: 10 minutes per biome; 1 hour for 5-6 biomes

Task

The instructor brings to class several "biome trash bags," i.e., bags full of items that represent a certain biome (the example of a rainforest trash bag is presented below). If your class is small, give each student one item; if the class is large divide the class into biome groups and give each group one trash bag. Students should brainstorm about where (i.e., what biome) the item(s) came from and how environments were affected in its production. Example: Collecting nuts is not intrusive whereas cutting down trees to make furniture can be.

If students or individual groups cannot make the connections between the items in each biome bag, assist them with leading questions or ask the rest of the class to suggest ideas. If students have some background information on different biomes, this will go much faster. If the activity is presented as a detective story, students usually have a lot of fun. To make the task more challenging, you may add to each bag one "red herring" item which does not belong to the biome the bag represents. Students need to identify that item and explain why it does not belong in it.

This activity can be used as a lead-in to discussions about the sustainable use of certain biomes or as preparation for Activity 1.5 in which students learn about a biome in depth.

Note: Undoubtedly, many products from the tropics/tropical forests are produced at the expense of the natural environment and at the expense of native peoples and others living there. Many students will bring an already heightened environmental awareness of these issues to the classroom. There are, however, some experimental and some well-established ways to use tropical natural resources (e.g., in integrated agroforestry) that do not degrade the environment or exploit native cultures, indigenous knowledge, or destroy the natural basis for local ways of life. The discussion around these issues can easily become polemic and polarized.

Ideas for a rainforest trash bag

Rainforest clearing for consumption elsewhere:

❑ rubber ball	Native Brazilian rainforest; British import to Malaysia to grow in plantations; issues of slavery; dislocation of natives
❑ chewing gum packet	Chicle for gum
❑ Brazil nuts, cashews	"Rainforest crunch" (Ben & Jerry's ice cream); agroforestry
❑ bananas	Plantations; slavery; external control of best farm land
❑ chocolate wrapper	Cacao beans; plantations
❑ sugar packets	Deforestation for plantations; slavery initially; external control of farm land
❑ coffee tin	Ditto
❑ cosmetic items (e.g., Body Shop)	Tropical plants provide ingredients for cosmetics and medicine

❑ a newspaper article on deforestation	Topicality of problem; social/environmental problems

Rainforest trees used to make single-use items

❑ chopsticks
❑ small rainforest wood items

Rainforest animals used as pets

❑ snake	(Bring in toys, photographs)
❑ lizard	
❑ frog	
❑ monkey	
❑ butterfly	
❑ parrot	

Other items

❑ styrofoam cup	Production and burning produces CFCs >> stratospheric ozone depletion >> potential human and environmental health effects
❑ Coca-Cola can	Original formula contained cocaine
❑ MacDonald's wrapper	Rainforest transformation to rangeland for beef production
❑ insect repellent	Rainforests have the largest total species reservoir on earth, especially among the insects
❑ medicine bottle	Plants as potential sources for new medicines/cures
❑ matchbox/empty lighter	Symbolizes burning of rainforest >> release of CO_2, destruction of the "lung of the world"; increased greenhouse effect
❑ small globe	Global view: only one earth!

Activity 1.3 Film: "Preserving Our Global Environment"

Goal

This activity raises students awareness for the interconnectedness of social and environmental concerns in different countries, cultural, and environmental contexts. Students are asked to take their own position after viewing the film and discussion the issues in class.

Skills

✔ critical film understanding
✔ class discussion
✔ writing a short reaction paper (optional)

Material Requirements

Film "Preserving our Global Environment" (1994; VHS, 53 minutes)

available from: World Resources Institute
Washington, DC 20006
Tel.: 1-800-822-0504
Order code: EDPGV

Faculty receive a significant discount. The film is accompanied by a 12-page instructor's guide providing background information, study questions, and references.

Note that videos can also be rented via interlibrary loan. Be sure to allow plenty of time to obtain a copy of the film.

Time Requirements

1 class/lab session (53 minutes for viewing the film plus discussion time)

Task

The film focuses on three urgent global environmental issues: population growth, biodiversity loss, global warming -- how they interrelate, and what actions can be taken to protect the environment. These problems are illustrated through case studies from Africa, Central America, and the US.

The film provides a good opportunity to alert students to the values underlying the viewpoint from which these problems are discussed in the film. How do they compare with other viewpoints students have heard? Do students agree with the viewpoints expressed in the film? (Other discussion questions are suggested in the accompanying guidebook that comes with the film.) Discuss these issues in class and/or ask students to write a short reaction paper to the film.

Activity 1.4 Field Trip

Goal

Field trips are meant to acquaint students with their own environment, to sharpen students' observational skills, to make learning fun, and to illustrate the relevance of abstract concepts.

Skills

✔ keen field observation
✔ note taking
✔ writing a field report

Material Requirements

access to the field/site locations

Time Requirements

one-half to one day

Task

We all live in some biome. Students may know their environment (more often than not they are rather unfamiliar with it!), but they may never have looked at it from a biogeographical perspective. This is a good opportunity to take students outside the classroom and to show them what's typical and unique about the biome they live in.

Ask students to keep a field trip journal, to take notes of their observations and the explanations throughout the trip, and to write up a two-page summary about the habitats, ecosystems, or portions of the biome that they saw. Encourage them to draw sketches, take photographs, bring field guides and binoculars on the trip, and wear appropriate shoes and clothing.

You might find it helpful to have large maps available to orient students and to place the site they visit into the larger landscape context. The field trip may be linked to later activities suggested in Unit 3. Plan ahead accordingly.

Activity 1.5 Writing a Biome Biography -- Drawing a Biome Profile

Goal

Students become intimately familiar with a biome of their choice. They collect as much biogeographical (and related) information as they can and synthesize and present it to the class in a creative and clear way.

Skills

✓ data search
✓ synthesis of information
✓ creative presentation of "biome biography" (including oral, visual, and other means)

Material Requirements

Access to maps and other biogeographical resources (library, items in a student's possession)
Student Worksheet 1.5 (provided)
Supporting Material 1.5 (optional; provided)

Time Requirements

1-2 days outside preparation for students
1 class session for student presentations

Task

Students choose a biome, or the instructor assigns them one. The task for each student is to teach the rest of the class about their biome *in a creative way*. If the class is quite large, students should organize into groups, research and prepare outside the class, and present their biome collectively. On the assigned day, each biome group has 15 minutes to present their biome. Generally students will show and describe:

- ❑ location and extent of the biome (world map)
- ❑ climate
- ❑ vegetation
- ❑ animals
- ❑ environmental threats
- ❑ human alterations
- ❑ products derived from the biome
- ❑ economic benefits

The quality of this activity can be variable, but it is always great fun and a wonderful learning experience. Students who tested the module said that teaching their classmates was challenging. You may want to give your students some basic guidelines about presentation and conveying this material effectively. Students' creativity can be boundless: they may bring in plants, stuffed or live animals (check for institutional restrictions and give safety reminders!), they may dress up in parkas, play tapes of new age or native music typical in their region, offer baskets of fruits and nuts, bottles of wine; or show slides and tourist souvenirs brought back from trips they have taken.

An interesting resource for students to start out with is the map of Ecoregions of the United States (*Supporting Material 1.5*) and its accompanying report (see McNab and Avers [1994] and LaRoe *et al.* [1995] in the annotated bibliography in the *Supporting Materials* section of this module).

You may want to ask students to prepare a 1-2 page summary of their biome and make these summaries available to everyone <u>after</u> the presentations. The format of that summary could be standarized if you so choose.

1 Introduction to Biogeography and the Human Dimensions of Global Change

Student Worksheet 1.1

Activity 1.1 Which biome are you in?

Do you know what biome you are in? Can you list five ways in which you are linked to the biosphere? Answering these questions is what this activity is all about.

Before you come to class the next time, remember to bring something from your home that represents or symbolizes a biome. You may think of anything from a house plant, to a type of fruit, to photographs of animals, to items made out of a natural fabric or material, and so forth.

During the class session you will present the thing(s) you brought in to your classmates and tell them a bit about it:

- ❑ (If it's not obvious) What is it?
- ❑ What is it made of?
- ❑ What is it used for? What does it mean to you?
- ❑ How does it relate to the biome?
- ❑ What can you say about the biome judging from this item/plant/animal? (For example, you may think about how and where the animal lives or the plant grows and how that is a form of adaptation to the biome it represents.)

Be creative! Find the most interesting thing in your house and tell a good story about it! If a map is available, show your classmates where the biome is located that you refer to. If you don't know exactly where the biome can be found, go to a map library or use an atlas to find this information prior to the class session.

Student Worksheet 1.2

Activity 1.2 What's this got to do with me?

Many of us live a kind of life that is very much protected from the natural environment. If it's 110 °F outside, we can crank up the air conditioner and stay in a comfortable 70 °F. Most of us don't grow our own food, and thus we don't have to contend with early or late frost, drought or floods that may destroy our crops, or any of the other vagueries of nature. In fact, sometimes we don't even know exactly where the food that we find in the grocery store comes from. And hardly anyone wonders where the clothing that we wear comes from, or the furniture we have in our houses. How was it produced? How did the production process affect the natural environment. Our culture, the technologies we have at our hands, and our choice of lifestyle have removed us quite a bit from the natural environment.

In this activity, we will see how we are connected to different biomes, i.e., where some of the products that we use in our daily lives come from. And we will investigate the implications of using and producing these items.

Your instructor will bring in a bag full of "stuff" that represents a certain biome, and it's your job to figure out what biome you're dealing with. Think of yourself as a "biome detective." If you do this in small groups, discuss among yourselves how the items were produced and how the environment was affected in that process. Think also about who produces these materials and how you are connected to the people who produced them.

Here is an example: You might find a can of coffee in your bag; so it's about coffee (forget the can for a moment). Where is coffee grown? How is it grown? Are a lot of fertilizers and pesticides used in the process? How much water is needed? And who grows it? Are these rich people? Poor people? Do the people who grow the coffee earn a good living from it? And so on.

Notice how what you eat, wear, and use has far-reaching implications, socially and environmentally. You just may find yourself connected to the rest of the world!

Student Worksheet 1.5

Activity 1.5 Writing a Biome Biography – Drawing a Biome Profile

In this activity, you will either choose or be assigned to one biome, and you will familiarize yourself with it as much as possible. Your task is to write a biome biography -- describe and explain a biome to the best of your ability.

You may use whatever information source you can find: maps, atlases, textbooks, journal articles, the Internet or World Wide Web, field guides, slides, photographs, items that represent the biome, cultural artifacts, tapes, and so on. Be creative but don't overwhelm people with too much information. Just assume that your classmates know nothing about this biome, that you will introduce them to it, and that you want them to remember it. So your biome biography has got to be special!

Examples of things you may want to include in your biography are issues like:

- ❑ location and extent of the biome (world map)
- ❑ climate
- ❑ vegetation
- ❑ animals
- ❑ environmental threats
- ❑ human alterations
- ❑ products derived from the biome
- ❑ economic benefits

Your instructor may ask you to prepare a summary of this information for everyone in your class.

1 Introduction to Biogeography and the Human Dimensions of Global Change

Answers to Activities

No specific answers to Activities 1.1 through 1.5 are provided here because they are highly dependent on the instructor's and students' choices of biomes, the items they bring to class, the field sites they visit, and so on. Here are a few general guidelines, however, as to what students should take away from the activities in Unit 1:

- Students should recognize their multiple connections to the biome they live in and to the environment (ecological and social) more generally.
- Students should demonstrate creativity in their presentations.
- Students should demonstrate that they have consulted a variety of information sources (depending on the objectives of the class, you may for example give extra credit for using the World Wide Web).
- Students should begin to be familiar with the global distribution of biomes and ecoregions.
- Students should begin to see the connections between flora, fauna, climate, hydrology, and other physical characteristics of the earth (soil, geomorphology, geology).

2 Production

Background Information

Understanding Production and its Limiting Factors

In the first unit, we began to familiarize ourselves with some principles of biogeography and how biogeography and the human dimensions of global change are related. One of the questions raised there was how production (in agriculture, forestry, and so forth) may change as the climate and other environmental factors change. In this second unit, we look at this question in detail.

Let's begin with the basic question, what is production? We commonly associate production with yield. The units can be volume or mass. Increases in mass may be defined as the increase in gross biomass (for example, the growth of trees), as the increase in the number of individuals (as in the case of population increase), or as the increase in a subset of mass production (for example, in seed, fruit, or forage yield, a subset of total production).

Organism types, species, and individuals differ in their productivity and in the efficiency with which they convert resources into biomass. Efficiency varies throughout the life cycle of the organism and depends on the environmental setting. The organismic and the environmental factors that influence this efficiency and productivity are called limiting factors, because in combination, they determine (limit) efficiency and productivity. For example, **cool-season plants** optimize the conversion of atmospheric carbon dioxide to plant carbon at about 20° C. Cool-season plants, like wheat, rice, and soybeans, use the **C3 photosynthetic process**, in which the first product in the sequence of biochemical reactions involved in photosynthesis has three carbon atoms. C3-plants use some of the solar energy they absorb in a process known as photorespiration in which CO_2 fixed by plants gets reoxidized and released again as CO_2. Because photorespiration is repressed under conditions of increased CO_2, the photosynthesis of C3-plants under conditions of increased CO_2 will lead to the production of more biomass (i.e., increased productivity). **Warm-season plants** on the other hand, like corn, sorghum, millet, and sugarcane, optimize the conversion of atmospheric carbon dioxide to plant carbon at about 35° C. They use the **C4 photosynthetic process** in which the first product in the sequence of biochemical reactions involved in photosynthesis has four carbon atoms, a more efficient process than the C3 process. C4-plants are optimal photosynthesizers under current CO_2 conditions, and thus are likely to be less efficient photosynthesizers in a carbon dioxide enriched world (cf. Rosenzweig and Hillel 1993: 209).

In commercial agriculture, economic yield is usually more important than biomass yield. For example, farmers may choose to plant a low-yield, but high-price crop instead of a high-yield, low-price crop. In this case, efficiency is defined as the return on cash investment rather than biomass production return on energy and carbon input. Much of what drives the intensification of agriculture through technological innovation, resource inputs, and structural changes is the search for financial efficiency, or in other words, profit. For example, government crop subsidy programs are a major driving force that farmers respond to by selecting which crops to grow. This aspect of global biomass production is not predicted by the production potential of the environment and for that reason is not considered any further here. Instead, let's direct our attention toward the non-agricultural biogeographical systems.

What factors govern how much biomass is produced? We discuss six that apply to all biogeographical systems and two additional ones that apply in the case of managed ecosystems and/or agricultural systems.

Genetic factors

Different organisms have different productive potential owing to their genetic make-up in any given site.

Geographic location and site factors

Places in the landscape (hills, valleys, and uplands) have local variations in solar radiation, water, and soil resources, and are subject to different types and frequencies of disturbances (processes like fire, wind fall, erosion, landslides, etc. that eliminate or decrease the short- to long-term viability of an organism). By "breaking up" the soil or the interactive web of organisms, disturbances make colonization by new organisms possible. For a summary of recent research on disturbance, invasion, and habitat change see Lodge (1993). On the other hand, already established organisms may or may not offer the kinds of ecosystemic niches, resources, and potential for interactions necessary for an arriving organism to find its new habitat there. The appropriate habitat for plants and animals simply may or may not be available or accessible.

Trophic level and biotic interactions

The diversity of organisms and their distribution among the **trophic levels** (position of an organism in the food web) are among the limits to long-term production. The degree of mutual benefit derived from sharing resources is important to long-term productivity. When passenger pigeons and squirrels sustain themselves by consuming acorns, they also provide for the oak's dispersal by not consuming all the acorns they carry away. Patterns of buffalo grass suggest that the bison destroyed plants by wallowing, but this also created opportunities for spreading the grass when the seed burrs carried in the bison's hide until rubbed off in the wallowing process.

Not all sharing relationships are harmonious, nor do all mutually beneficial relationships maximize production. Such a relationship may have benefited buffalo grass populations, but it probably replaced more productive plants. Some plants have a positive growth response to being grazed on, but the grazers' presence is not required. Winter wheat is sown in the fall and is sometimes grazed to stimulate **tillering** of the newly emerged seedlings before winter dormancy sets in. **Tillering,** the increase in the number of emergent reproductive and vegetal shoots, creates more robust plants that produce a higher seed yield. The truest form of mutual benefit/dependence is in the **symbiotic** relationship between two organisms, a relationship in which both organisms mutually require the presence of the other. A good example is the symbiosis between fungi and algae that form lichens. Though these species evolved as independent species, they are now so mutually evolved that neither can survive alone. Similar relations exist between animals and digestive bacteria.

Pests, predators, disease, and other disturbances

This is really a special case of the third factor, biotic interactions. Pests, predators, and diseases are aspects of a changing, interactive biotic system, aspects that capture or divert the resources needed for production of a given organism. They may even eliminate some organisms from the landscape.

Time

Production varies over time as a result of the temporal variability in all of the above factors. A clear expression of this factor is the seasonal change of productivity: temperature, light, and water change in most biomes over the course of the year. Consequently, productivity increases and decreases over the course of the year. Both too little of a resource or too much of any will reduce production.

Management

The term management implies control of factors of production. Given the complexity of any biotic system, management strategies usually aim to affect only a few of the limiting factors of production.

Price

While not going into any detail about the market forces that affect agricultural production, it is important to mention that price fluctuations affect which products are grown. Commonly, production is therefore biased toward crops that will yield the most net cash return per unit of land rather than the most biomass. Occasionally, the result is the same, but usually it is not.

The Food Web

Places in which biotic interactions take place -- habitats for short -- can be viewed as systems in order to understand the process of production. The concept of the **food web** is one example of place as a system. In the food web, each organism and energy reservoir interacts with its surroundings by **transfers of mass and energy** (Cunningham 1994). The flows of mass and energy can be expressed in transfer budgets. They are altered by direct human intrusion into the process (e.g., harvesting, fertilizing, irrigating) and by indirect human alteration (habitat reduction, forage removal affecting grazers and carnivore production, deliberate or accidental introduction of a new organism, inadvertent changes in atmospheric temperature or chemistry affecting plant life, wildlife habitat, and crops). The alteration of these flows sometimes involves the redirection of resources to other uses (e.g., water capture for agricultural crop irrigation or car washing). Humans also invade the ecosystem energy storage compartments for particular purposes. For example, plowing soil increases the oxidation of soil carbon (organic matter), and forest cutting removes carbon and nutrients stored in the standing biomass.

Modeling Material and Energy Flows Through the Food Web

Modeling is one way to enhance our understanding of nutrient and energy flows. It is important to remember that models are simplifications of reality; they are never as complete and dynamic as the real system we try to understand. Precisely because in building a model we select what we think are the most important elements and processes of a system, models are a helpful means to understand some of the interactions taking place and the relative importance of the elements in a system. The food web shown in the food web slide show is no exception (see ***FOODWEB.FLC***).

Models like the food web can be operationalized as simulation models. We use simulations as tools to understand the interdependence among parts of a system (e.g., between nutrients and production) and to see how a system behaves if one of the elements is changed, or in other words, how sensitive the overall functioning of a system is to a change in one of its components. For instance, we can use such models to explore how production might change if we alter the availability of water or nutrients from the atmosphere. A test of this kind is called **sensitivity analysis.**

With regard to global change studies, such analyses are extremely useful and are also frequently used in the common case where we do not know what impacts, say, a temperature increase of 2 °C would have on the productivity of wheat. The questions are: how sensitive is wheat to such a change in temperature, and in which direction will its productivity change; toward higher or lower productivity?

The simple three-compartment simulation model of the nutrient cycle (Gersmehl 1976) we will use in the activities operates under the laws of conservation of mass and energy (which says that mass and energy may change the form in which they appear, but they can't really be lost). This simulation model is formulated as an equilibrium or steady state model in which, after a certain number of iterations, the relative allocation of nutrients among compartments stabilizes. In the real world, forces that control the fluxes among compartments are not constant, not synchronous (they do not occur at the same time), and are seldom predictable. Thus, we cannot use the model to predict the future. We can, however, use it to illustrate how changes in one part of the system cascade through the system to produce different futures, providing all other things are held constant. This, of course, can be done only in the abstract world of models.

With a model such as the nutrient cycle simulation model we can see why plant biomass, soil, and litter conditions differ dramatically over large geographic areas or at different points in time. The quality of the modeling outcomes depends on how adequately we know the relevant attributes of the range of places we try to model.

Human Interactions with the Food Web

Human life depends on the food web. As omnivores, humans depend on intrusion into more than one trophic level. We are special omnivores because we manipulate primary and herbivore productivity to meet specialized wants (agriculture, natural resource management and use). Via mechanized agriculture we try to direct all production toward satisfying our own special wants. The result is substantially reduced diversity, which, in turn, denies resources to other organisms. Monocultures, the most extreme example of such specialized production systems lacking in diversity, are of concern because they affect a wide array of environmental processes and organisms. Anything we do to change the suite of plants and animals or their abundance alters the nutrient and energy fluxes (uptake, respiration, and fallout) of affected spaces. These altered flux rates cascade through the system, affecting other trophic levels.

All human activities that affect land cover change mass and energy balances. Loss of vegetation accelerates erosion and deposition elsewhere. Release of greenhouse gasses alters the loss of long-wave-length terrestrial radiation and is thought to result in climate warming. Many other feedbacks in the global system, their nature and magnitude, remain unknown. Specifically we do not know how much of the greenhouse effect will be mitigated by increases in humidity and cloud cover that reduce incoming solar radiation.

We also do not understand how simple policies aimed at mitigating problems in part of the system stimulate radically different responses from place to place. Some of these mitigation strategies stimulate responses that are the opposite of what the strategies were meant to do. Just as business managers try to minimize tax impacts (by maximizing benefits from the tax code), farmers respond to land conservation reserve programs by conserving some land and at the same time plowing other land to maintain the same base. Alternatively, they may quite intentionally fail to use effective soil conservation measures in order to qualify for another government program aimed at paying farmers to retire vulnerable lands. A third example of unintended effects of mitigation strategies is the case where the government pays farmers not to plant so as to keep marginal pieces of land out of production while maintaining farmers' income. In some dramatic cases, this led to a perceived scarcity of land and consequently caused the land values of both the cultivated and the preserved land to go up. Finally, this resulted in the ironic situation of farmers plowing under the (marginal) "virgin" rangeland to meet the market demands for cultivated land and to boost their incomes. Thus the attempt to conserve land ultimately lead to greater use (and in some cases to degradation) of the land.

2 Production

Instructor's Guide to Activities

Notes on the Food Web Slide Show

The slide show presentation on the food web and trophic states is designed to run under Auto desk, Animator Pro player program (***ANIPLAY.EXE***). Each step is a single frame and is intended to be advanced manually. See the technical notes on how to operate ***ANIPLAY.EXE*** in the *Supporting Materials* section of this module. The individual frames are described below. The slide show builds the complexities of trophic levels in the food web in a stepwise procedure. If computers are not available to run the slide show, print-outs of each frame are included in the Supporting Materials section from which overheads or copies can be made.

Although this model of the food web is a gross abstraction of reality, it contains enough detail to demonstrate how human interactions with the system have effects throughout the environment. Humans interact directly and indirectly with both the compartments and the flows. A description of each graphic frame follows:

Graphic frame 1

Geochemical reactions alter the gaseous composition of the air contained in the voids of rocks. This process created the atmosphere. This process was and continues to be important in creating the atmosphere. In the absence of living organisms, gas exchange between the porous surface material and the atmosphere is driven by changes in air pressure or the addition or loss of water. The classical definition of soil (the medium of plant growth) does not apply to soils at this stage. Severe human impacts made some sites revert to this abiotic state (or nearly so). The most visible examples are the effects of acid fallout from metal smelter stacks (for example in Ducktown, Tennessee and Sudbury, Ontario).

Graphic frame 2

Vegetation may be composed of a suite of organisms from simple algae and large plants. Different plants in different amounts at different stages of development extract nutrients from the soil at different rates. Thus the uptake rate depends on the composition of the assemblage. Respiration rates, growth, and fallout are also dependent on the composition of vegetation. The external factors of solar radiation, temperature, and rainfall regimes regulate all transfer rates.

The respiration of plants is the primary mechanism for removing carbon dioxide from the atmosphere and replenishing the oxygen supply. Photosynthesis fixes carbon from atmospheric carbon dioxide into plant organic matter and releases the oxygen back into the atmosphere. Fire (very rapid oxidation) releases the carbon sequestered by the plant.

The array of organisms that make up the vegetation is controlled by a genetic materials budget that involves immigration, local evolution, and local extinction rates. The diversity of these plants also depends on how well they are able to share local nutrient and energy resources.

The litter volume on the soil surface depends on fallout and decomposition rates. Initially, litter decomposition was a purely mechanical/chemical process; with the evolution of organisms, decomposition became a biogeochemical process.

Graphic frame 3

Micro-organisms (from insects to bacteria) contribute to the nutrient cycle by converting nutrients from plant litter to a form that plants can use again for regrowth.

Environmental changes, direct human actions that change the litter composition, cultivation that stirs or buries the litter, and the use of insecticides or other chemicals that change the environmental chemistry alter the mix and populations of micro-organisms.

Graphic frame 4

Herbivores (aphids, grasshoppers, gophers, elephants) add a trophic level to the food web. The array of organisms that make up the herbivore trophic level is also controlled by a genetic materials budget that involves immigration, local evolution, and local extinction rates. The diversity of these animals also depends on how well they share the local nutrient and energy resources.

The amount of biomass supported at this level is limited by the amount of primary production (vegetation) that is suitable for the available animals. We commonly judge habitat quality for single grazers by our observation of their preferences, but that can be misleading. Grazers (like gazelles) are adaptable to new types of forage, provided that the forage meets the grazers' palatability, digestive, and nutrient requirements.

Graphic frame 5

Carnivores (wolves, cats, hawks, etc.) add yet another trophic level to the food web. The array of organisms in the carnivore trophic level is also controlled by a genetic materials budget that is the result of immigration, local evolution, and local extinction rates. The diversity of these animals also depends on how well they share the local nutrient and energy resources.

The amount of biomass supported at this level is limited by the amount of herbivore production that is suitable for the available animals. Assessing habitat quality for a single carnivore is more complex than assessing it for a grazer because carnivores require habitats in which the food source (i.e., their prey) is sufficiently exposed. Carnivores are adaptable to new types of food sources, provided that these food sources meet their palatability, digestive, and nutrient requirements.

Graphic frame 6

In some places a second level of carnivores provides another reservoir for sequestering nutrients briefly before returning them to the surface litter. These animals, like the eagle, which eats carnivorous fish as well as herbivorous rodents, usually are not solely dependent on first-level carnivores.

Other examples of trophic levels include.

- ❑ Carrion eaters, like vultures, consume dead animals they did not kill;
- ❑ Omnivores (animals like bears, crows, and some rodents) eat both plants and animals;
- ❑ Symbiotic organisms, like digestive bacteria, depend on the host animal and are required by the host to extract nutrients from food. Symbiotic organisms are not detrimental to each other. Plant versions of symbiosis include a wide variety of lichens that are formed by algae and fungi living together, neither of which can live separately;
- ❑ Parasites that provide no benefit for the host animal or plant and gain no benefit from its death. Some examples are fleas, lice, schistosomes, and parasitic plants (orchid, mistletoe); and
- ❑ Disease organisms (bacteria and viruses) may kill the host they depend upon for life and dispersal.

Activity 2 Nutrient Cycling Simulation Model

Goals

The primary goal of this activity is to help students see the impacts of both human-induced and non-human-induced changes in the mass and energy flows that affect the production of the biosphere. A secondary goal is for students to learn how to perform simple sensitivity analyses that test the effects of human intrusion into the biological production process by changing the nutrient storage compartments and the rates of flows between compartments. The activity allows students to examine the outcomes of changes in three very different biomes, and to compare the changes that take place in the simulation model versus those they may have predicted.

Skills

✓ navigating and using a spreadsheet
✓ understanding the principles behind and the usefulness of simulations

✓ critical thinking
✓ writing a rounded, balanced summary of impacts of human interactions with biomes

Material Requirements

A copy of the spreadsheet ***NUTCY4.wb1*** (provided on disk)
Spreadsheet software, preferably *Quattro Pro for Windows 5.0* (or higher), or *EXCEL* 4.0
A copy of ***FOODWEB.FLC*** with ***ANIPLAY.EXE*** (provided on disk); alternatively overheads made from the print-outs of the slides (originals provided)
Student Worksheet 2 (provided)
Supporting Material 2 (provided)
Suggested readings (see below)

Suggested Readings

Unit 2, *Background Information* (provided)
Supporting Material 2 (provided)
Relevant sections on nutrient cycling from the readings in the Appendix (provided)

Time Requirement

2 lab sessions depending on students' familiarity with spreadsheets for simulation and discussion

Task

Students should read the *Background Information* of Unit 2 and the additional reading on production and nutrient cycling (*Supporting Material 2* and the additional readings provided in the Appendix) before they tackle this activity. The activity can be run as a demonstration with student inputs about what a selected type of environmental change might mean for the biosphere (in particular biospheric productivity). As an aid in starting the discussion, the slide show ***FOODWEB.FLC*** builds a schematic multiple trophic level model of nutrient cycling. Use that slide show to build a common knowledge base with students.

On the *Student Worksheet* the concepts behind the nutrient cycling model and how it represents an ecosystem are explained in more detail. The application of the model in this activity focuses on three environments, each of which has experienced radical direct human alteration or faces the threat of substantial human alteration if global warming becomes a reality. The first is the **selva** biome, which over the past two decades has been subject of intense scientific debate because of the rapid clearing of tropical rainforest in the Amazon Basin and in Southeast Asia (often for grazing). The global change issue here is primarily the release of carbon (sequestered by the huge standing biomass) into the atmosphere as carbon dioxide, a greenhouse gas. The second biome is the **tundra** which is underlain by permanently frozen soil (the term **permafrost** derives from the fact that the soil does not completely thaw during the summer months). The last biome is the **steppe**, much of which has been converted to prime agricultural land for grain crops over the past 200 years.

Running the simulation on nutrient cycling in and of itself won't be much of a challenge to most students. Detailed instructions are provided for each consecutive step students need to follow. During the testing phase of this module, students indicated that after about the third biome simulation, there was nothing new to learn from handling the spreadsheet itself. To avoid "busy work" and disinterest, divide the class into biome groups and have each group run only the 2-3 simulations for their particular biome. Coming back together afterwards, they should discuss and answer the questions asked with each run (questions accompanying the 8 simulations), compose the summary of impacts on biomes (summary paper), and then present it (possibly with print-outs of the summary graphs and tables) to the rest of the class. If the class is very big, have several groups per biome, and compare and complement each group's answers with those of others who dealt with the same biome.

Note: The ***NUTCY4*** model was developed in *Quattro Pro for Windows 5.0*. It has been successfully imported into *EXCEL 4.0* on a Power Mac 6100, but this transfer does not work in reverse.

2 Production

Student Worksheet 2: Nutrient Cycling Model

Preparation

Before you begin this activity, make sure you have read the *Background Information* of Unit 2, especially the *Food Web* section, and *Supporting Material 2* provided by your instructor on nutrient flows in an ecosystem, the simplified ecosystem nutrient cycle model, and the three biomes we will use as examples in this simulation. Your instructor may have also assigned you additional readings on nutrient cycling. All these will deepen your understanding of this activity.

Purpose of the Activity

In this activity, we will test what happens to three different biomes when we interfere with nutrient cycling, the mass and energy flows in these systems. By "we" we mean us, running this computer simulation model, but if we take a step back from the modeling for a minute, "we" can also stand for humans more generally who interact with, and thereby affect, nutrient flows in ecosystems. It is even possible to think of the changes we evoke in this computer model as examples of what could happen through large environmental changes whether they are brought about by purely natural processes or through anthropogenic causes.

Instructions

① Copy the file ***NUTCY4.WB1*** to your own diskette or the hard drive of your computer.

② Open the file in *Quattro Pro for Windows 5.0®* or import it into *EXCEL®*. The following descriptions are specific to handling a spreadsheet in *Quattro Pro for Windows*, but spreadsheet software is quite similar across many different brands, and even the differences between PCS and Macs are insubstantial. Your instructor will help you out if you are not using *Quattro Pro for Windows*.

③ Familiarize yourself first with this spreadsheet and the terminology that is commonly used to orient oneself in it: A **spreadsheet** is simply a computerized table made up of **rows** (going across) and **columns** (going down). Both columns (enumerated with the letters of the alphabet from left to right) and rows (enumerated with numbers from the top to the bottom) have **headings**, names, so one knows what the numbers in the cells mean. When a column and a row intersect, they form a **cell**. Each cell has a so-called **cell address**, for example "A3" which means that the cell is located at the intersection of column A and row 3. Most cells (or at least the ones of interest for any calculation) have **cell entries**, i.e., something written into them. Cell entries can be words, letters, or numbers. Let's relate all these terms to our example here: In the *NUTCY4* spreadsheet (see also the print-out below), columns represent nutrient storage volumes in each compartment (litter, soil, and biomass), followed by nutrient flow rates between compartments, respectively. The rows contain the numbers (one row for each year) that result from the simulation (see point ④ below). Cell A3 in this case has the cell entry "Selva" -- the name of the first biome for which we run the simulation.

④ Before we "run a simulation," let's understand what that means. With your mouse cursor click on cell C4. This cell currently has the cell entry "6." If you paid close attention, you saw another part of the spreadsheet change just as you clicked on that cell: a grey-shaded area between the **tool bar** (the row of little icons) and the column letters. This grey-shaded area is very helpful because it gives you, on the left, the cell address (in this case, it says A:C4 because we are on page A of this spreadsheet in cell C4), and it gives you an in-depth look at the cell entry. You thought all that was in cell C4 was the entry "6" -- and now look at all that's in the cell: a whole string of cell addresses, mathematical symbols, and numbers! In short: a **cell formula**. The number 6 is simply the end result of the calculations prescribed by this cell formula.

The reason why we take the time to look at this cell formula is not that you should learn how to translate your ideas of what happens in an ecosystem into mathematical symbols and formulas -- that has already been done for you. Instead, the purpose is to understand that each number from row 4 onward is the result of such calculations and that the results from the calculations for any year enter in a more or less complicated fashion into the calculations for each following year. If you click on other cells in row 4 (which contain the results for year 1 of the simulation), you will find that some cell formulas are rather simple whereas others are more complicated. Some simply rely on the cell entry above (the beginning conditions of the nutrient cycle) and thus are readily calculated, while others rely on cell entries from the row above <u>and</u> from neighboring cells, i.e., other values for the first simulated year, which can thus only be calculated after the simple calculations have been completed. The degree of complication of these cell formulas simply reflects the fact that ecological relationships are more or less complex. Or in other words, it demonstrates that the simple measures you can take in the field are the result of many complex interactions among ecosystem compartments.

We can now see that all calculations ultimately go back to the entries in row 3. Therefore, we say that row 3 controls the rate of transfer between compartments at each annual step in the simulation. A "simulation," then, is just another word for computations of future states of something based on past and present data for that thing (e.g., storage and flows within an ecosystem). "Running a simulation" in a general sense means that you use a model to test what happens to it when you alter the inputs. A simulation allows you to understand the importance of such input change, and it allows you to see how whole systems change over time. In practice, running a simulation for a certain biome in a spreadsheet that comes with all the cell formulas, like *NUTCY4*, simply means changing the numbers in the row that controls all further calculations -- and that's it! You can page down to the last row and you will see that the simulation is set as a

270-year run (i.e., all calculations are repeated 270 times to get results of storage and flows for 270 years). The outcomes of all years are reported. The embedded graphs (a bar chart and a curve of cumulative changes) show how the nutrient storage changes in the litter, the biomass, and in the soil over the time for which we simulate nutrient flows.

⑤ So now, let's run a simulation for one of the other biomes. To the right of the simulation columns are examples of flow rates that model nutrient flows in three extreme environments, the selva, steppe, and tundra (followed by various alternative biome models, respectively). Copying these cells into the fields starting with column A, row 3 resets the starting storage for all compartments and the transfer rates between linked compartments.

Again, any change to the values in row 3 will automatically run the model for the newly inserted value(s).

To copy, click with your mouse cursor on one of the cells that contains the biome name of your choice and hold down the left mouse button as you move the cursor across the end of that row. This will block out this portion of the row. Now click on the copy button (or use the Edit menu or a key combination), click with your cursor on cell A3 and, finally, click on the Paste button (or use the Edit menu or a key combination). Within a few seconds, the computer will have recalculated the simulation for 270 years given these new entry values. You will also observe that the embedded graphs change, since the graphs automatically display whatever values have been calculated in the simulation.

Here are the steps involved in copying: block -- copy -- move to destination -- paste

⑥ In sequence, copy the fields for selva, steppe, and tundra into the cells starting in A3. You will perform a simulation experiment on each of these biomes in a "natural" state (e.g., selva) and for an alternate scenario of each of these entries (e.g., selva2) with the environmental change described below. As you go along, answer questions about the natural biome as well as the effects of changes on the system. Notice that only in one case will you be asked to actually alter cell entries (selva3). For all others, compartmental storage values and average flow rates for the altered biome are provided. To make better sense of the numbers, inputs of nutrients from rain, weathering rock, fertilizer, and removal of nutrients and biomass (through harvest) can be integers ranging from 0 to 9. The flows between compartments and losses from the system are decimal fractions ranging from 0.00 to 1.00.

Here are the descriptions and questions for each of the biomes and their altered states:

Selva

The selva, the common lowland tropical rainforest, is composed of a wide variety of broad leaf, evergreen trees. The standing biomass is huge, and fallout rates are low. Nutrient inputs from the atmosphere are high because of the very high rainfall. After you have run the selva model, record the storage values in each compartment and record losses to the system at year 270 (values from the last row) in the table below. When you look at the graph, you will find that the nutrient storage curves level off after some time, i.e., the amount of nutrients stored in each compartment doesn't change much after a certain time. The speed at which the system storage values stabilize depends on the slowest transfer rate. Examine the annual values to determine how quickly the relative storage among the compartments stabilized. Which compartment changes the slowest, which the fastest? Which compartment stores the most, the least, and the intermediate amount of nutrients? In a few sentences try to explain the storage amounts and the time it takes to reach that level. Given what you know about the storage amounts of nutrients in the three compartments we looked at in this run, what would you predict would happen to the fertility of this biome if you deforested it? Make a note of your observations on an extra sheet of paper.

Selva2

One of the forces that drives land cover change in this region is that the world market price for hamburger encourages ranchers in Brazil and in other tropical countries to convert rainforest into grazing land for cattle. Selva2 is a sensitivity experiment to see the effects of this land use change decision that involves cutting, burning, and sowing grasses. Copy the Selva2 values to A3. The starting conditions in the storage compartments are the same as those at the end of the Selva simulation; the flow rates are average rates for the kind of land use change that we try to simulate here. Describe on an extra sheet of paper how and why you think uptake and fallout change with a burning of the forest and planting of grass for cattle ranching. Think of what the changes would be in nutrient losses resulting from erosion and leaching. Record the storage values in each compartment and losses to the system at year 270 in the table below. If you're not sure about how flow rates would change, discuss this with a classmate.

Selva3

The starting conditions for the storage compartments are again as those at the end of the Selva simulation, and the flow rates are average rates for the land use described here. Under this sensitivity analysis, the land users are subsistence farmers practicing swidden or slash-and-burn agriculture: tropical forest is allowed to establish itself for a period and then small plots are cleared, burned, farmed, and abandoned when the soil fertility drops. In this farming practice, no materials are permanently removed from the site, and a wide range of crops are grown together (a practice called inter-cropping). This type of farming, though labor intensive, maximizes the use of soil and climate resources. In our example, the farmer uses the land for only two years and lets it be fallow for 38 years (it is allowed to grow back to forest, seeded by the trees that are close by). To mimic this 40-year rotation of swidden agriculture, selected cells in column K (fallout) must be modified. However, we will not mimic the cycle for the same plot over 270 years, but rather show only a few slash-and-burn periods. (Imagine you looked at one area in the biome, and every so often this area would happen to undergo the slash-and-burn disturbance.) To simulate this, insert the following formula into cell K84, i.e., add it on to the formula already in that cell by clicking with the cursor at the end of the existing formula: [+0.95*J83] (do not type in the brackets) and copy this new formula to the following cells: K85, K164, K165, K244, and K245. Record the storage values in each compartment and losses to the system at year 270 in the table below. How different are the outcomes of **Selva3** and **Selva2**? What would happen if the rotation were shortened, say, to two years of farming, then only 15 years of fallow, and then cutting the forest again? (You may find it easier to answer this question by simulating such a rotation, using the same addition to the cell formula, and copying that extended cell formula to a greater number of cells.)

Steppe

Steppe vegetation is dominated by grasses, which vary widely in their traits. Steppe grasses lose most of their annual production to grazers or fallout during the winter or the dry season. They are mostly perennial (except in California, where they have been largely replaced by annual grasses) and tolerant of defoliation by grazing animals, fire, and drought-induced leaf drop. Nutrient uptake is relatively slow because of the low demands of these much smaller plants. In semi-arid climates, the loss of nutrients in runoff water is slight and the leaching of nutrients from the soil is rare because the negative water balance keeps the soil water below **field capacity** (the amount of water soils can hold against the pull of gravity). For leaching of soluble minerals to occur, soil water must rise above field capacity. After you have run the steppe model, record the storage values in each compartment and losses to the system at year 270 in the table below. Compare, as you did for the **selva** biome, the storage amounts and stabilization times for soil, litter, and biomass. Now imagine cultivating a steppe for grain production. What changes in storage values and flow rates would you predict? How come?

Steppe2

Much of the world steppe biome has, in fact, been converted to fields for grain production. Grains are domesticated grasses whose seeds are used as food for livestock or humans. This biome has become the major grain region ("bread basket") of the world (including the corn and wheat belts of the U.S., Argentina, Australia, Russia, Ukraine, and China). In the case presented here, the values reflect the mechanized monoculture of the Midwest. It involves high inputs of chemical fertilizers to replace the nutrients removed in the grain. This simulation starts with the ending storage conditions of the **Steppe** simulation. The flow rates, again, are the average rates for the changed land use. Describe on an extra sheet of paper how uptake and fallout change to reflect a plowing of the grasslands and annual planting of corn. Suppose that fertilizers are applied at rates slightly larger than those supplied by rain. What changes in nutrient losses would result from erosion and leaching? Record the storage values in each compartment and losses to the system at year 270 in the table below.

Steppe3

The starting conditions are again the same as those at the end of the **Steppe** simulation, and the new flow rates typify the land use described here. The farming practice here uses a four-year crop rotation common in the Midwest up to 1950 (corn, corn, oats, hay/pasture). Chemical fertilizers were not used, and the only exports from the farm were meat and dairy products. Animal wastes (manure) were returned to the fields as fertilizer. Moreover, plant densities were much less than in **Steppe2**. A variety of institutional factors stimulated the abandonment of this type of farming in the heart of the corn belt. These included: (1) a rise in land costs and occasional high grain prices; (2) advice from universities, the U.S. Department of Agriculture, and lending institutions; (3) incentives to use land carelessly through the availability of profitable government farmland retirement programs; and (4) technological developments in equipment, plant genetics, and agricultural chemicals. Record the storage values in each compartment and losses to the system at year 270 in the table below. Describe the differences in the impact of this farming strategy with that used in the **Steppe2** experiment.

Tundra

Tundra is underlain by permanently frozen ground, **permafrost**, that prevents nutrient leaching. Plant growth is restricted by the short growing season (light and temperatures). After you have run the tundra model, record the storage values in each compartment and losses to the system at year 270 in the table below. Compare again, as you did for the selva and steppe models, how storage amounts and stabilization rates differ for soil, litter, and biomass. How do you explain what you see in the simulation? How would you expect the environmental conditions for plant growth (storage and flow rates in all three compartments) to change if you assumed that global climate change would significantly raise the average temperatures in the higher latitudes (say by 3 °C)?

Tundra2

The loss of substantial carbon stores from the selva forests, the oxidation of soil carbon in cultivated steppes, and the release of carbon from burning fossil fuels are expected to double the carbon dioxide content of the atmosphere by about 2060. It is hypothesized that this doubling of CO_2 will induce global climate change that will include substantial warming at high latitudes, particularly in winter. Many scientists expect that global warming will have a pronounced impact on the extent of permafrost and the abundance of plants adapted to a frozen substrate (soil and rock material plants grow on). A sustained increase in the depth of thawing would be seen as an indicator that global warming was occurring. Assume for this run that global warming has thawed the permafrost, allowing nutrients to be leached and lost from the system. On an extra sheet of paper, describe the changes in uptake and fallout that would result from a thawing of the tundra. Assume no significant change in vegetation (270 years is too short a time for a complete thaw of the permafrost and for significant in-migration of new plants to occur; thus there would be no radical increase in uptake in the short run). Record the storage values in each compartment and losses to the system at year 270 in the table below.

Table 1: Year 270 Summary

	Litter	Soil	Biomass	Runoff	Leach	Removal
Selva						
Selva2						
Selva3						
Steppe						
Steppe2						
Steppe3						
Tundra						
Tundra2						

Write a 1-2 page critical summary of the impacts of the human-induced environmental changes you have modeled. Use your notes from the above 8 simulations to write this overall assessment of these impacts.

When you come back to class for the next session, be prepared to present to your class what you found in your simulations, how you would explain them, and what you concluded from these observations about the types of human-induced environmental changes you simulated in this model.

2 Production

Answers to Activity 2

Activity 2: Nutrient Cycling Simulation Model

By manipulating the nutrient cycling model, students should gain insight into a variety of human interactions with the environment. Three distinct (and in some respects extreme) environments are chosen. Attached below are prints of the summary tables of each simulation and the respective embedded graphs for:

- ❑ an original selva
- ❑ a conversion of selva to grass for grazing
- ❑ selva occasionally and partially cut and burned for swidden agriculture
- ❑ an original steppe
- ❑ a conversion of steppe to continuous corn production with fertilizer added
- ❑ a conversion of steppe to a four-year crop rotation
- ❑ an original tundra and
- ❑ a tundra altered by global warming that thaws the permafrost, but does not allow for new species to invade yet.

The model values used to generate the graphs are contained in the summary spreadsheets. The values for year 270 are summarized in the *Year 270 Summary* table below.

Where computer facilities are not available for the demonstration or the hands-on use of the *NUTCY4* model, the outputs for each of the scenarios can be used instead. Instructors may make print-outs of the table containing the initial conditions in each biome, run the simulation for each to obtain the associated graphs for each biome, and then provide students with these and the tables of the human-altered cases to use as a basis to answer the questions. For the **Selva3** case it may be preferable to use the line graph rather than the histogram because the impact is more obvious there.

Notes on the simulations

Students should have taken notes like the following while running the simulation. They form the basis for their final assessment (summary paper).

Selva

Litter storage rates stabilize after a couple of years, soil storage rates stabilize after 15-20 years, and biomass storage values stabilize after about 120 years. The first rate reflects the time it takes under tropical climate conditions for litter to be produced, decomposed, and taken up via the soil. The time it takes for the nutrient storage in soils to stabilize reflects the time it takes to establish a dynamic equilibrium of edaphic (soil) processes, including physical processes, biochemical processes, and the establishment of a viable soil fauna and flora in the face of fast-growing biomass. Finally, nutrient stabilization in biomass takes the longest because tropical tree species need this amount of time to reach full maturity and for the ecosystem to establish itself as a mature, self-organizing web of physical and biotic interactions in dynamic equilibrium.

Students should be able to predict that because most of the nutrients are stored in the biomass, and not in the soil, that in the case of a large-scale deforestation, most of the fertility of this biome would be lost. (You may want to compare this to a temperate forest situation where nutrients are largely stored in the soil.)

Selva2

This simulation shows what students predicted for a deforestation of **Selva**. The invoked change results in a severe drop in biomass and a drop in uptake rates because the grasses do not extract as much water and nutrients from the soil as do large trees. Similarly, the standing biomass is almost completely lost to fallout on an annual basis. This is why the fallout rate is more than 99%. It reflects the character of a grassland where grazing and leaf decomposition take away most of the standing biomass.

Selva3

Because the soil depletion is not total and a plot is commonly only a few tens of meters across, which facilitates recolonization by neighboring species, the natural recovery after a slash-and-burn and farming episode is fairly rapid. In comparison to the **Selva2** situation where the biomass is removed completely and continuously, biomass nutrient storage is able at least to approach pre-cutting values. But the simulation of repeated slash-and-burn cycles shows that biomass storage doesn't quite reach pre-cutting levels. A shortening of the fallow-period would result in an ever smaller nutrient recovery, i.e., an eventual loss of fertility.

Steppe

Soil storage of nutrients is highest in this biome, with litter and biomass falling vastly behind. The storage differences reflect both the relatively dry climate, which doesn't allow much soil leaching and slows down litter decomposition, and the biomass that in and of itself isn't able to store large amounts of nutrients, but which produces biomass year after year and then accumulates as litter and eventually as a nutrient reservoir in these most fertile soils. Students should be able to conclude that cultivation of a steppe soil would result in a quick nutrient loss whose speed is determined by the uptake of nutrients by grain, the increase of leaching and erosion, and the lack of supply of litter for decomposition, hence replenishment of soil fertility.

Steppe2

The cultivation of corn affects the steppe in several ways: as predicted at the end of the **Steppe** simulation, there is a quick loss of nutrient storage from the soil. The initial boost in soil storage is simply the result of applying water (irrigation) and fertilizer and plowing the soil, all of which combine to accelerate the decomposition process. The initial boost in litter storage reflects the plowing under of grasses. Both erosion and leaching increase with a more open soil (corn is renowned for its accompanying erosion because it covers the ground so incompletely), but are still much less than in the humid tropical climates (much less rainfall). Fallout rates close to 100% reflect the annual harvesting of corn (total removal of biomass), and the increase in the uptake rate shows that corn needs more nutrients than grasses.

Steppe3

The pre-1950s cultivation and crop rotation shares some of the characteristics described above but generally seems to be more conserving of soil fertility. Litter and biomass storage values hardly differ after 270 years of this type of cultivation, but the soil fertility has declined, if more slowly than in **Steppe2.** Because average soil coverage is higher, leaching and runoff are less than in **Steppe2.** Similarly, biomass uptake is an average over a four-year crop rotation that includes lower-yield (less nutrient-intensive) crops. Finally, the return of some nutrients via manuring also slows down the loss of nutrients from the soil.

Tundra

In this biome, litter stores most of the nutrients, with soil storing much less and only little more than biomass. Plants, as mentioned on the student worksheet, grow slowly and generally are small and low to the ground. Soils are mostly frozen, and generally thin and poor in nutrients, allowing soil processes to proceed only slowly. Litter decomposition is restricted by temperatures and hard plant material, which explains the relatively large accumulation of nutrients in litter. The most important effect of climate change for the tundra may be the increase in temperatures which will enhance plant growth, evapotranspiration, litter decomposition, and nutrient leaching from the thawing ground. Thus, students could predict an increase of nutrient storage in biomass along with a large loss of nutrients from the soil. Because litter decomposes faster, the storage there will decrease as well.

Tundra2

Interestingly, the changes predicted at the end of **Tundra** hold only for the first few years. Over time, litter storage of nutrients and biomass accumulation all increase, if slowly. This can be explained by a general amelioration of the growing conditions for plants given higher temperatures. Soil processes accelerate, leading to more fertile and better drained soils. Plant growth is stimulated by increased soil fertility and a longer growing season (light conditions stay the same, but frost leaves sooner and comes later in the year). And the increase in biomass translates to larger litter amounts. In short, assuming current species can adapt rapidly enough (as this model does), global warming is expected to increase the productivity of the tundra biome.

In the short essay that concludes this activity, students should summarize and discuss these observations and explanations. Check their essays for

- a critical understanding of human interactions with the natural environment
- the ability to think in systems terms, i.e., the ability to see how changes in one compartment of the ecosystem affect other compartments and processes
- a good understanding of the differences among the three biomes discussed
- the ability to abstract from the numbers they simulated to the larger underlying principles and processes that bring about the simulation results.

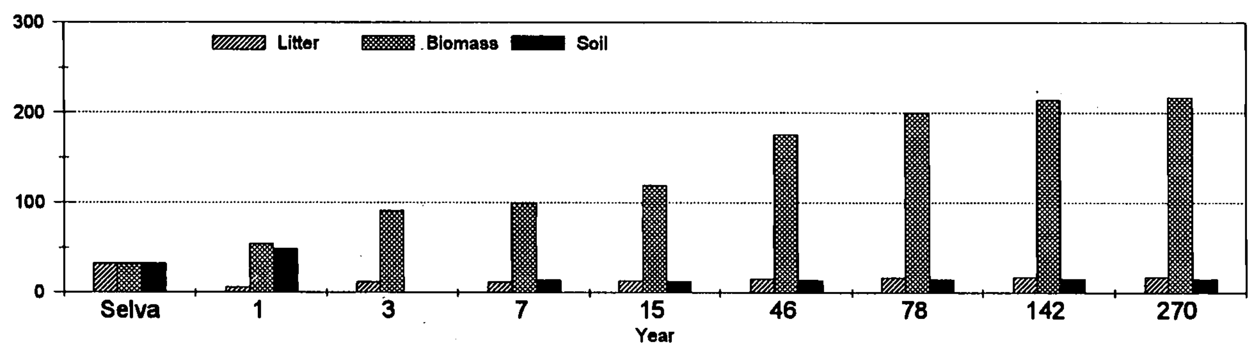
Table 2: Year 270 Summary (Results)

	Litter	Soil	Biomass	Runoff	Leach	Removal
Selva	18	16	270	5.80	6.20	0
Selva2	17	18	6	7.58	4.42	0
Selva3	17	15	213	5.74	6.15	0
Steppe	17	207	10	0.85	4.15	0
Steppe2	32	130	26	3.18	6.49	0.3
Steppe3	11	136	7	0.77	4.07	0.2
Tundra	60	6	2	3.00	0.00	0
Tundra2	92	72	38	1.85	2.15	0

The following pages are print-outs of the year-270 summary graphs that students should produce in this activity.

Summary table

Year 0	Rain in	Litter store	Litter Runoff	Litter 2 Soil	SOIL store	SOIL Leach	Rock 2soil	Bio. Uptake	Bio-mass	Fall out	Fert-ilize	Re-move
Selva	**9**	**33**	**0.33**	**0.80**	**33**	**0.40**	**3**	**0.70**	**33**	**0.05**	**0**	**0**
1	0	6	10.89	26.40	49	13.20	3	23.10	54	1.65	0	0
3	0	12	3.60	8.72	0	5.64	3	9.86	91	4.28	0	0
7	0	12	3.85	9.34	14	7.64	3	13.36	99	4.50	0	0
15	0	13	4.33	10.50	12	4.16	3	7.28	119	5.90	0	0
46	0	16	5.16	12.50	14	5.63	3	9.85	175	8.71	0	0
78	0	17	5.53	13.40	15	5.96	3	10.44	200	9.95	0	0
142	0	17	5.75	13.94	15	6.16	3	10.78	214	10.69	0	0
270	0	18	5.80	14.05	16	6.20	3	10.85	217	10.85	0	0



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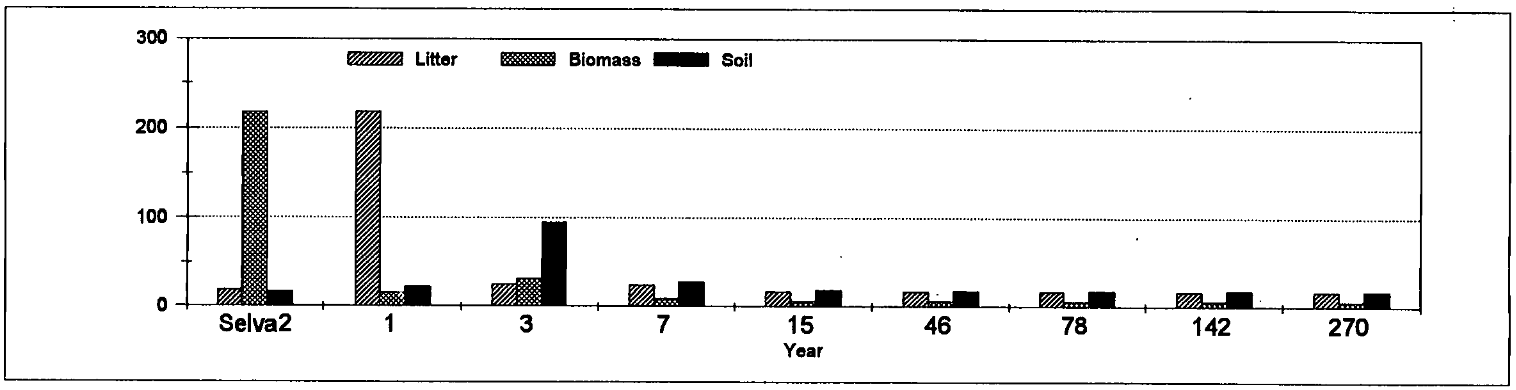
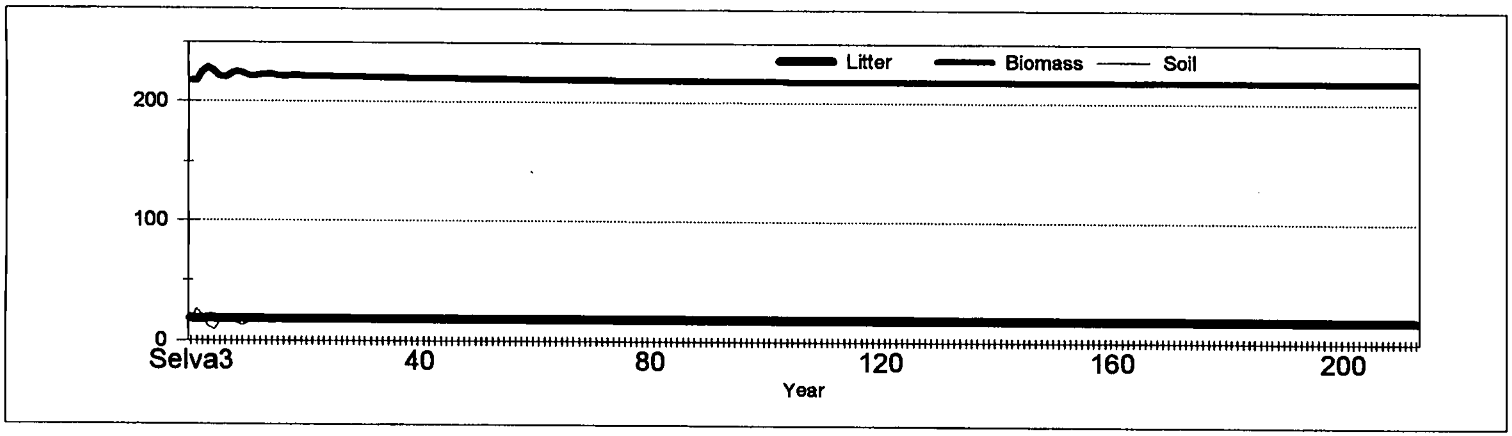
Summary table

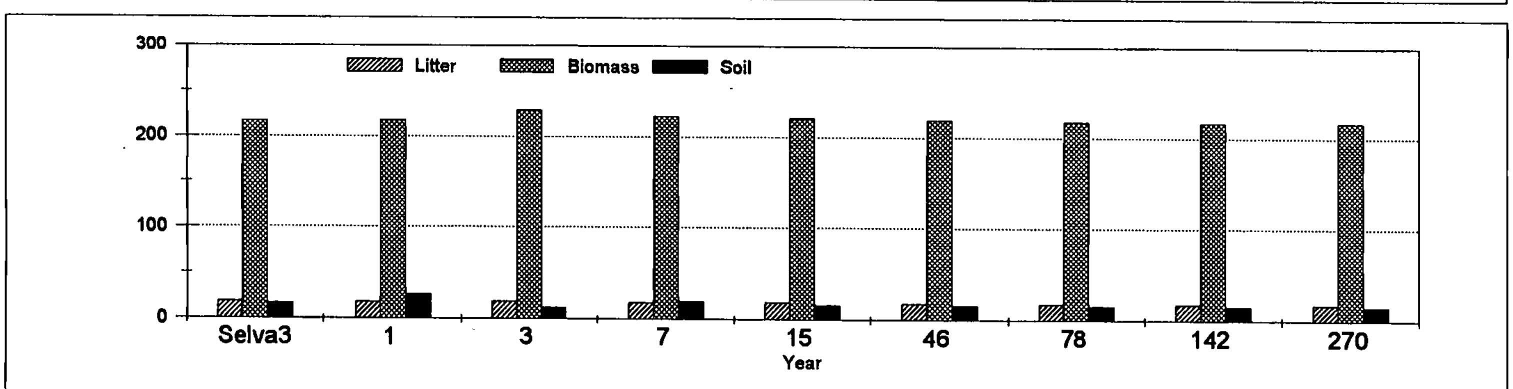
Year 0	Rai in	Litter store	Litter Runoff	Litter 2 Soil	SOIL store	SOIL Leach	Rock 2soil	Bio. Uptake	Bio-mass	Fall out	Fert-ilize	Re-move
Selva2	**9**	**18**	**0.45**	**0.40**	**16**	**0.25**	**3**	**0.30**	**217**	**0.95**	**0**	**0**
1	0	218	8.10	7.20	22	4.00	3	4.80	16	206.15	0	0
3	0	24	25.45	22.62	95	25.44	3	30.53	31	6.98	0	0
7	0	24	14.56	12.94	28	7.02	3	8.43	9	9.83	0	0
15	0	17	7.78	6.92	18	4.55	3	5.46	6	5.55	0	0
46	0	17	7.58	6.73	18	4.42	3	5.31	6	5.31	0	0
78	0	17	7.58	6.73	18	4.42	3	5.31	6	5.31	0	0
142	0	17	7.58	6.73	18	4.42	3	5.31	6	5.31	0	0
270	0	17	7.58	6.73	18	4.42	3	5.31	6	5.31	0	0



Summary table

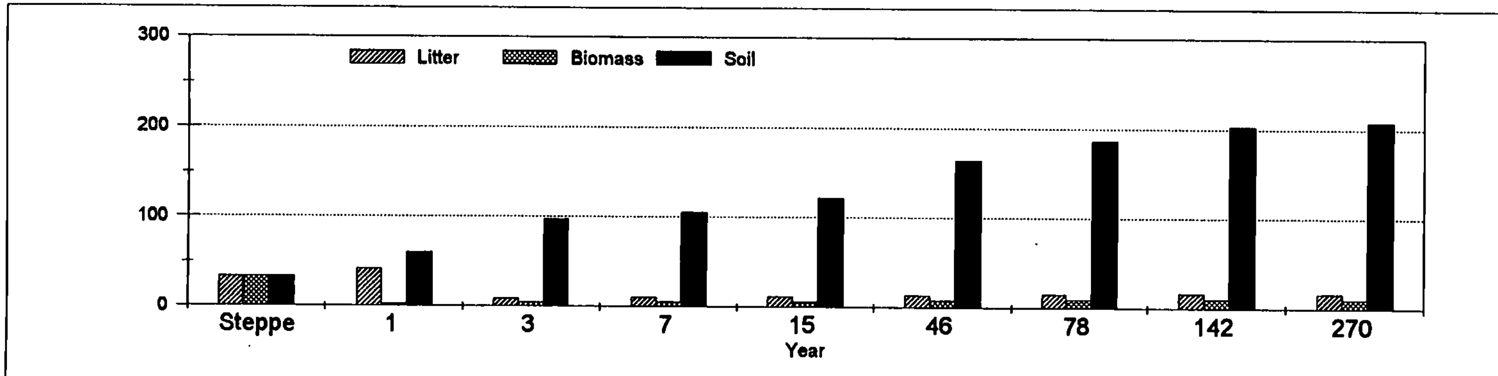
Year 0	Rai in	Litter store	Litter Runoff	Litter 2 Soil	SOIL store	SOIL Leach	Rock 2soil	Bio. Uptake	Bio-mass	Fall out	Fert-ilize	Re-move
Selva3	**9**	**18**	**0.33**	**0.80**	**16**	**0.40**	**3**	**0.70**	**217**	**0.05**	**0**	**0**
1	0	18	5.94	14.40	26	6.40	3	11.20	217	10.85	0	0
3	0	18	5.81	14.07	12	8.64	3	15.11	229	11.24	0	0
7	0	18	5.84	14.16	19	7.92	3	13.87	223	11.00	0	0
15	0	18	5.88	14.26	15	5.81	3	10.16	221	11.12	0	0
46	0	18	5.83	14.13	16	6.23	3	10.90	219	10.96	0	0
78	0	18	5.81	14.09	16	6.21	3	10.87	218	10.90	0	0
142	0	18	5.80	14.06	16	6.20	3	10.86	217	10.86	0	0
270	0	18	5.80	14.06	16	6.20	3	10.85	217	10.85	0	0





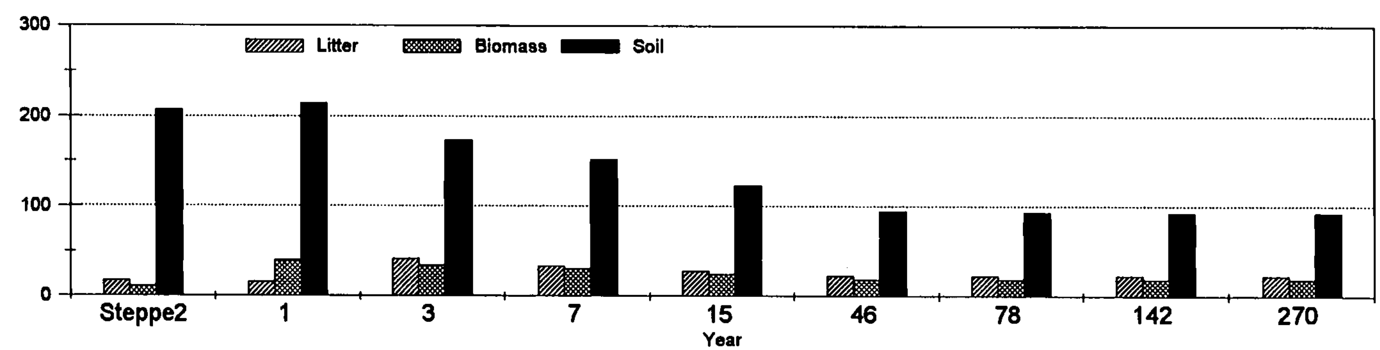
Summary table

Year 0	Rai in	Litter store	Litter Runoff	Litter 2 Soil	SOIL store	SOIL Leach	Rock 2soil	Bio. Uptake	Bio-mass	Fall out	Fert-ilize	Re-move
Steppe	**4**	**33**	**0.05**	**0.80**	**33**	**0.02**	**1**	**0.05**	**33**	**0.99**	**0**	**0**
1	0	42	1.65	26.40	60	0.66	1	1.65	2	32.67	0	0
3	0	9	0.61	9.76	97	1.82	1	4.56	5	2.97	0	0
7	0	11	0.52	8.38	105	2.06	1	5.15	5	5.03	0	0
15	0	12	0.58	9.20	122	2.40	1	6.00	6	5.90	0	0
46	0	14	0.71	11.35	164	3.27	1	8.16	8	8.11	0	0
78	0	16	0.78	12.45	186	3.71	1	9.29	9	9.26	0	0
142	0	17	0.83	13.27	202	4.05	1	10.12	10	10.11	0	0
270	0	17	0.85	13.52	207	4.15	1	10.37	10	10.37	0	0



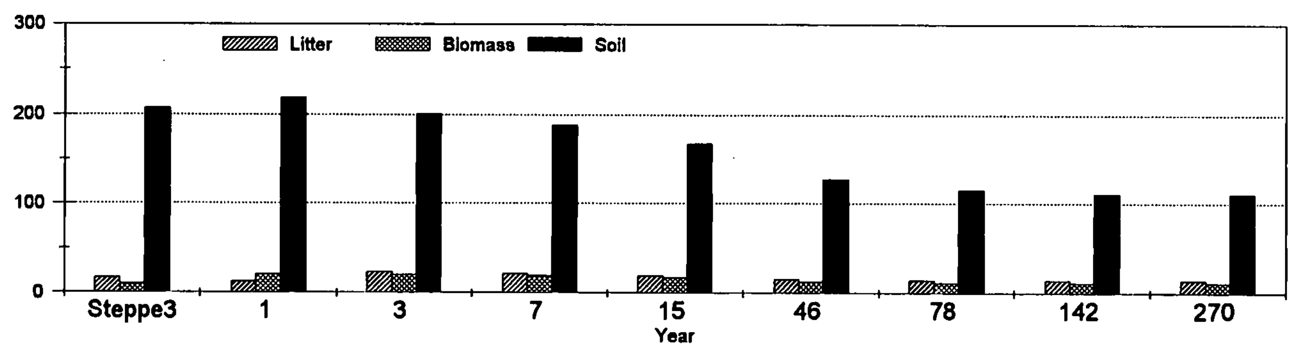
Summary table

Year 0	Rain in	Litter store	Litter Runoff	Litter 2 Soil	SOIL store	SOIL Leach	Rock 2soil	Bio. Uptake	Bio-mass	Fall out	Fert-ilize	Re-move
Steppe2	**4**	**17**	**0.20**	**0.99**	**207**	**0.05**	**1**	**0.20**	**10**	**0.99**	**5**	**5**
1	0	16	3.40	16.83	214	10.35	1	41.40	40	9.90	5	1.97619
3	0	41	9.03	44.70	173	8.93	1	35.74	34	40.78	5	1.721323
7	0	33	6.94	34.34	152	7.83	1	31.31	30	31.03	5	1.506051
15	0	28	5.69	28.15	122	6.25	1	24.98	24	24.34	5	1.201283
46	0	23	4.56	22.58	95	4.74	1	18.98	18	18.10	5	0.912435
78	0	22	4.48	22.19	93	4.64	1	18.56	18	17.67	5	0.892194
142	0	22	4.48	22.16	93	4.63	1	18.53	18	17.64	5	0.890818
270	0	22	4.48	22.16	93	4.63	1	18.53	18	17.64	5	0.890812



Summary table

Year 0	Rain in	Litter store	Litter Runoff	Litter 2 Soil	SOIL store	SOIL Leach	Rock 2soil	Bio. Uptake	Bio-mass	Fall out	Fert-ilize	Re-move
Steppe3	**4**	**17**	**0.10**	**0.99**	**207**	**0.03**	**1**	**0.10**	**10**	**0.99**	**0**	**3**
1	0	12	1.70	16.83	219	6.21	1	20.70	20	9.90	0	0.61
3	0	23	2.29	22.65	200	6.14	1	20.45	20	21.20	0	0.6
7	0	21	2.13	21.04	188	5.73	1	19.09	19	18.86	0	0.56
15	0	19	1.91	18.95	167	5.07	1	16.91	17	16.65	0	0.5
46	0	15	1.52	15.02	127	3.83	1	12.78	13	12.47	0	0.38
78	0	14	1.40	13.85	115	3.47	1	11.55	11	11.23	0	0.34
142	0	14	1.36	13.43	111	3.33	1	11.11	11	10.78	0	0.33
270	0	14	1.35	13.39	111	3.32	1	11.07	11	10.75	0	0.33



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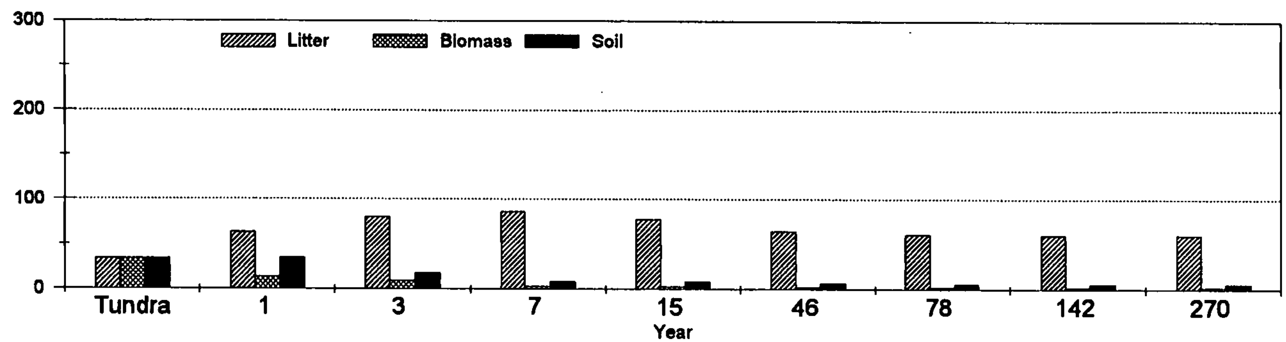
Summary table

Year 0	Rai in	Litter store	Litter Runoff	Litter 2 Soil	SOIL store	SOIL Leach	Rock 2soil	Bio. Uptake	Bio-mass	Fall out	Fert-ilize	Re-move
Tundra	**3**	**33**	**0.05**	**0.03**	**33**	**0.00**	**0**	**0.30**	**33**	**0.90**	**0**	**0**
1	0	63	1.65	0.99	34	0.00	0	9.90	13	29.70	0	0
3	0	80	3.64	2.19	18	0.00	0	7.70	9	10.28	0	0
7	0	86	4.33	2.60	8	0.00	0	2.56	3	3.01	0	0
15	0	77	3.91	2.35	8	0.00	0	2.41	3	2.44	0	0
46	0	64	3.22	1.93	6	0.00	0	1.95	2	1.95	0	0
78	0	61	3.05	1.83	6	0.00	0	1.83	2	1.84	0	0
142	0	60	3.00	1.80	6	0.00	0	1.80	2	1.80	0	0
270	0	60	3.00	1.80	6	0.00	0	1.80	2	1.80	0	0



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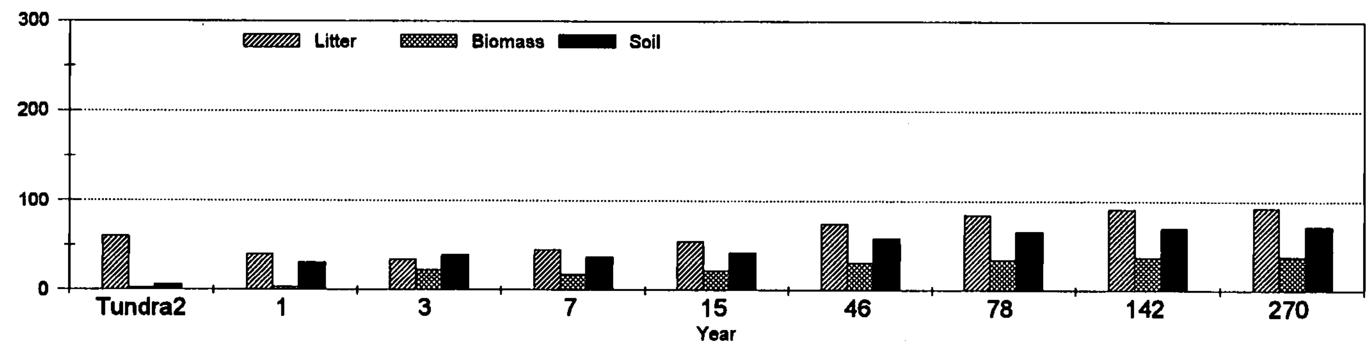
Summary table

Year 0	Rain in	Litter store	Litter Runoff	Litter 2 Soil	SOIL store	SOIL Leach	Rock 2soil	Bio. Uptake	Bio-mass	Fall out	Fert-ilize	Re-move
Tundra2	**3**	**60**	**0.02**	**0.40**	**6**	**0.03**	**1**	**0.50**	**2**	**0.95**	**0**	**0**
1	0	40	1.20	24.00	30	0.18	1	3.00	3	1.90	0	0
3	0	34	0.58	11.59	39	1.30	1	21.65	22	14.55	0	0
7	0	45	0.94	18.79	37	1.00	1	16.60	17	14.74	0	0
15	0	54	1.07	21.30	42	1.25	1	20.87	22	20.53	0	0
46	0	75	1.48	29.65	58	1.73	1	28.76	30	28.58	0	0
78	0	84	1.68	33.63	65	1.96	1	32.59	34	32.51	0	0
142	0	91	1.81	36.28	70	2.11	1	35.16	37	35.14	0	0
270	0	92	1.85	36.96	72	2.15	1	35.81	38	35.81	0	0



3 Pattern

Background Information

Abundance and Spatial Patterns of Distribution

The most readily available references to biogeographical patterns are vegetation maps at various scales. Maps, however, especially at coarser scales, usually hide some of the **variability** within the mapping unit (a polygon within the larger biogeographical unit) because they are generalizations of reality and thus do not show the entire geographic range of individual taxa (a class or category, e.g., a **species**). There are, however, other ways to show geographic distributions of organisms that illustrate the reported range of occurrence better. One may, for example, portray the differential abundances of taxa as rank order of abundance. To show differential abundance of species, one might use dots to represent the species density over a region. Such a dot map would tell you how many species can be found in an area, but not which ones. Other types of abundance maps may tell you how frequently one particular species or land use can be found in different areas (e.g., the hog distribution or alfalfa production [e.g., as yield per acre] across the United States).

Abundance maps of "naturally occurring" organisms are much less common because of the lack of data. Pollen analysts use fossil pollen to infer the distribution of trees and other species in the past to show the dynamics of species. Abundances of some grass species have also been mapped. These have all been small-scale maps of large regions or continents, so not very much detail is portrayed in these maps.

The abundance of many grass and tree species commonly exhibits high spatial variability. Differences in abundances at sites within a landscape (**local variation**) are frequently as large as those over greater distances (**regional variation**). These varied local patterns indicate that the regional distributions are not spatially continuous, as is implied by the use of **isarithmic lines** (lines of equal value like contour lines that connect points of equal elevation) on maps to portray such patterns. Cartographic theory holds that point symbols are the only appropriate way to show spatially discontinuous phenomena (point data). That is, we cannot presume to show the values that lie between control points unless we have reason to believe that the surface is spatially continuous (like air pressure where we can reliably interpolate between observation points).

Pattern and Disturbance

When we are able to look at regional patterns of plant distributions at the level of individual organisms, we see that species are not uniformly distributed throughout a landscape. At this scale of observation, we can see that the assumed relationship between climate and plant abundance does not really hold. Disturbances create opportunities for invaders, thus diminishing the relative role of climate in determining the abundance of certain species. Climate is of course involved in the creation of disturbances, particularly erosion, flooding, wind-fall, fire, and deposition, but there is a different link between plants and climate than has traditionally been gleaned from the study of regional to continental scale patterns.

At the landscape scale, local patterns reveal that the presence of any organism is the result of invasion at some point in time. Patterns are thus products of biotic interactions between colonists (those organisms already present) and invaders (those newly arriving) whose presence is often facilitated by **corridors** of disturbance. An aquatic example demonstrating this is the change in fish population in the North American Great Lakes (see Lodge 1993: 378-380). The native fish assemblage of the Upper Great Lake once was dominated by the lake trout and coregonids (the colonists), but then changed significantly with the construction of the Welland Canal in 1829 (the corridor and hydrologic disturbance) which allowed two marine species, the lamprey and alewife (the invaders), to reach the Upper Lake. Together with a number of other factors, this eventually led to a dramatic decline of lake trout and coregonid. An important point to make here is that the terms colonist and invader don't inherently carry any value judgement with them. It really depends on which species' viewpoint you take, whether you see this change in lake population as negative or positive. Invasion is generally viewed as negative when the invading species displaces another one that had special value for use (e.g., an endangered plant, a tree we harvest for some human purpose, or a very beautiful songbird). On the other hand, if this endangered or useful or treasured species successfully colonizes a new space, we welcome it (see the examples described in Root and Weckstein 1995; Oglesby and Smith 1995; Morse, Kutner, and Kartesz 1995).

Differences in pattern among the co-occurring organisms are thus dispersal patterns for the invaders and patterns of disintegration for earlier invaders. Pattern analysis shows that some distributions are random and have been for a long time. The occurrence of some species may still be controlled by disturbance patterns that are not spatially systematic (e.g., buffalo wallows), but that are ideally suited to establishment of the species (e.g., buffalo grass seed burrs carried on the hides of bison).

By modeling the processes of disturbance and dispersal that exist at the landscape scale over wider areas, we can begin to see how these regional patterns develop. Some conceptual models of pattern development through organism dispersal are presented in the next unit as a basis for understanding the contribution of these patterns to the diversity of organisms in a space.

3 Pattern

Instructor's Guide to Activities

Goals
The activity complements those in Unit 4, but pays closer attention to the geographic distribution patterns than to species diversity. The main goal is for students to understand that there are reasons for distribution patterns, rooted in the ecological requirements of individual species, in their interactions with the physical environment and other species, and in disturbance regimes that affect a particular habitat. A second goal is for students to recognize and critically assess the disturbance regime and its impacts on a particular species or habitat.

Learning Outcomes
After completing the activities associated with this unit, students should be able to:

- visually recognize biogeographic distribution patterns
- apply theoretical understanding of ecosystems to eco-*logical* explanation of patterns
- search and acquire data from local and regional resources
- do some informal interviewing
- critically assess human interactions with the environment
- creatively display species/habitat distribution patterns and human interactions with them

Choice of Activities
It is neither necessary nor feasible in most cases to complete all the activities in the unit. Instead, select two or more, covering a range of activity types, skills, genres of reading materials, writing assignments, and other activity outcomes. This unit includes the following activities:

3.1 What Does It Take to Make a Pattern?	-- understanding and detecting patterns
3.2 Adopt a Biome! Adopt a Species!	-- data search and 2-3 paper on biogeographic patterns and their reasons
3.3 What if...? Thinking about Patterns of Fragility	-- determining local disturbance regimes

Suggested Readings
Unit 3, *Background Information* (provided)

Morse, Larry E., Lynn S. Kutner, and John T. Kartesz. 1995. Potential impacts of climate change on North American flora. In *Our living resources: A report to the nation on the distribution, abundance, and health of U.S. plants, animals, and ecosystems*, LaRoe *et al.*, eds., 392-395. Washington, DC: Department of the Interior, National Biological Service (provided)

Activity 3.1 What Does It Take to Make a Pattern?

Goal
Students understand the concept "pattern" and recognize and explain the underlying processes and relationships that bring about patterns.

Skills
- ✓ brainstorming
- ✓ finding concrete examples for abstract concepts
- ✓ eco-logical thinking

Material Requirements
Student Worksheet 3.1 (provided)
The first suggested reading (see below; provided)

Time Requirement
In class: 5-10 minutes

Task
The activities suggested in this unit are good for use in pairs or groups. If you used some of the activities in Unit 1 (especially Activities 1.1 and 1.5) where students can choose to deal with one biome throughout the module, the activities here provide an opportunity for students to build on their initial work. This will lend cohesiveness to the module and give students a sense that their work matters.

Activity 3.1 helps students clarify the meaning of the term **pattern** and the underlying processes and relationships that bring them about. Ask students to read *Student Worksheet 3.1*, then have them either work in pairs, groups, or -- if the class is small -- all together to come up with the answers to the first few questions. If students work in subgroups, collect some answers from the entire class after a few minutes and discuss unresolved questions.

Then prepare students for Activity 3.2 (which they will do as a homework assignment.)

Activity 3.2 Adopt a Biome! – Adopt a Species!

Goal

Students apply what they learned in Activity 3.1 to a biome or a species of their choice. They recognize, describe, and attempt to explain biome or species distribution patterns by linking them to ecosystem processes and to relationships among species, ecosystem compartments, and components of the physical environment.

Skills

✓ analytical thinking
✓ map reading and interpretation
✓ search for biogeographic data (World Wide Web optional)
✓ geoecological/systems thinking

Material Requirements

Student Worksheet 3.2 (provided)
Suggested readings (provided)
Access to maps and local organizations concerned with natural resource management either by visit or phone (see further information given below)

Time Requirement

Several days of out-of-class preparation (depends on work done on the biome in previous activities)
1 class session of class presentations (maximum)

Task

Students choose a biome, habitat, or species that they would like to work on. Several options are described to them on the *Student Worksheet*. Students gather all kinds of biogeographical and ecological information about this biome/habitat/species aimed at recognizing and explaining spatial distribution patterns.

The instructor gives students one or several options of how to present this information to the rest of the class at a given date. Papers, posters, or slide shows with oral presentations are some examples.

Note: Activity 3.2 is a welcome occasion to use maps and enhance students' map reading and interpretation skills. If you plan to do both Activity 3.2 and 3.3, it is best to plan them together to avoid extra work.

Activity 3.3 What if...? Thinking about Patterns of Fragility

Goal
Students understand the concept of "disturbance regime" and see the connection between disturbance regimes and the development of spatial distribution patterns of species, habitats, or biomes. Especially if students use a local species or habitat, they have an opportunity to connect with their local environment and with the environmental groups that work to protect it.

Skills
✓ data search
✓ informal interviewing
✓ field observation
✓ analytical and systems thinking
✓ report writing (or writing in a different genre)

Material Requirements
Student Worksheet 3.3 (provided)
The second suggested reading (provided)

Time Requirement
Several days of out-of-class preparation, analysis, and preparation of a report
(In-class presentation optional)

Task
Ask students to read the short paper by Morse *et al.* to introduce them to the concept of disturbance and to get them thinking about the connection between disturbance regimes and the evolution of species or habitat distribution patterns.

The *Student Worksheet* includes step-by-step instructions for students on how and where to obtain the information they need to understand how disturbance regimes and spatial patterns are linked. The basic information needs are:

❑ biogeographical information about a habitat/biome/species (distribution patterns, ecological needs and relationships)
❑ list of potential disturbances
❑ list of disturbances presently occurring at the chosen site/region (and likely future disturbances)
❑ list of impacts of disturbances on species/habitat distribution
❑ list of realistic measures to restrict negative impacts on species distribution

Guiding questions will help students put this information together to explain how disturbance regimes affect species/habitat/biome distributions. Tell students in what format they ought to present their findings; papers, technical reports (environmental impact assessment of environmental protection measures), posters, or oral presentations are possible formats.

Encourage students to be creative and allow them pretty much free range as to the kinds of resources they will use. This will allow them to engage with the subject. One of the positive side-effect is that students will care more about their immediate environment!

3 Pattern

Student Worksheet 3.1

Preparation

Before you begin working on this set of activities, you should have read the Background Information of Unit 3. Your instructor may have assigned additional readings on abundance, ranges, and patterns of species distribution. These will help you complete the following activities.

Purpose of the Activity

In this activity we will look at patterns of species distributions and try to find some of the environmental, biological, and/or human factors that contribute to the particular distribution patterns you will find. We will look closely at the importance of scale in discerning patterns, and examine the role of disturbance in the evolution of distribution patterns.

Activity 3.1 What Does It Take to Make a Pattern?

Before we look at species distributions, let's think for a moment about the term "pattern." No, this is not an English class, but we use this word all the time -- are you aware of what it implies? What's a pattern? What are some other words you can think of to define or paraphrase "pattern?" (Brainstorm for one minute with your classmates and collect the words in the space below.)

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The key aspect of pattern is that some sort of relationship between two or more elements is implied, and that this relationship has a repetitive character, a regularity, to it. Examples include the panels of a quilt, behaviors of people, events over time, plant species in a habitat, or lines on a map. The panels are put together in a certain way to form a larger whole (the pattern of the quilt); particular events occur in certain intervals so that we recognize that they are holidays that happen every year at the same time; and so forth. So in a pattern, elements are arranged; they are put in relationship to each other. These relationships can be **spatial** (e.g., in a cornfield, you have another row of corn plants every 30 centimeters), **temporal** (e.g., migratory birds come back North at around the same time every year), or **logical** (e.g., alder trees need lots of water, so you find them along streams, lakes, or in other wet habitats). When elements are put together such that we cannot find any such relationship, we speak of a **random** pattern, i.e., the placement of any one element next to another is entirely haphazard, entirely arbitrary, and without obvious order. Below, make a list of at least five examples of patterns, including some based on spatial, temporal, and logical relationships.

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Patterns are useful for human cognition. Our brain has learned to recognize patterns as a way to short-cut time-consuming processing of countless bits of information, and that in turn helps our perception, orientation, understanding, memory, and reasoning. Recognizing patterns of species distribution is an aid in understanding why species occur in a certain place, i.e., we understand the eco-logical relationships between a species and its environment. Based on that understanding, we can make better decisions about species preservation (what kind of habitat does this wolf need in order to re-establish and reproduce here?), and we can make better predictions about the impacts of environmental change (what will happen to the salmon population if we put a dam in this river? Will this orchid go extinct if the climate warms by 2-3° C?)

Patterns can sometimes also be a hindrance to understanding underlying complexities. For example, when someone says droughts occur every ten years (maybe because her experience with droughts has somehow become blurred), implying that this rhythm is a natural phenomenon, this perceived regularity may have little to do with actuality and may stop this person from trying to find out the true causes of the droughts.

In the remaining activities of Unit 3 you will have an opportunity to distinguish some patterns and to try to understand the underlying relationships that bring the patterns about.

Student Worksheet 3.2

Activity 3.2 Adopt a Biome! -- Adopt a Species!

At the beginning of this module, you may have chosen to focus on one particular biome. If you did not, pick one now! Alternatively (especially in light of Activity 3.3), you may have a favorite plant or animal species, or one that you always wanted to learn more about. Or you may even have a particular disliking for some plant or species -- you can also work with that in this activity. Pick one with which you think you can have some fun, and go and find out all you can about it. Use maps, dictionaries, atlases, field guides for wildflowers, insects, trees, and so on, geography, biology, soil science, climatology textbooks, sources on the internet (World Wide Web), etc. Ask yourself the following questions:

- where and when does it occur?
- what is its life cycle/seasonal sequence?
- what are its typical behaviors?
- are there typical distributions, e.g., in a particular climate zone, on a specific type of soil or terrain, along water bodies (salt- or freshwater), found typically with a number of other species?

When you have all the information you want, put it together in a 2-3 page paper with illustrations, or create a slide show or a poster (your instructor will let you know what formats he or she can accommodate). Your main goal is to show and explain to the class what spatial and other patterns of distribution you found, and why you think that pattern looks the way it does. For example, if you find a tree species that likes only one type of soil, find out enough about that soil type and tree species to say why that may be so. If there is a typical sequence of habitats/species, what processes made it come about?

Student Worksheet 3.3

Activity 3.3 What if...? Thinking about Patterns of Fragility

Before you do this activity, you should read the following short article if you haven't already done so. (Your instructor may assign additional or alternative readings.)

> Morse, Larry E., Lynn S. Kutner, and John T. Kartesz. 1995. Potential impacts of climate change on North American flora. In *Our living resource: A report to the nation on the distribution, abundance, and health of US plants, animals, and ecosystems*. LaRoe *et al.*, eds., 392-395. Washington, DC: Department of the Interior, National Biological Service.
>
> This short research article examines the vulnerability (fragility) of different plant species to climate and other environmental changes. What is it that does or doesn't allow a species to adapt to altered (climatic) conditions? The article discusses rarity, vulnerability, dispersal, persistence, ability to migrate, disturbance, and landscape fragmentation in order to understand potential impacts on the abundance of species.

In this activity, you will do a little research on possible impacts of various kinds of disturbances on the patterns of distribution of a biome, habitat, or species. You may use the habitat or species you already learned about in Activity 3.2, or you may choose a new one (but that involves doing the groundwork of Activity 3.2 again).

A local or nearby example works best because in addition to having books and maps to consult, you can make phone calls or pay a visit to your local Audubon Society or Nature Conservancy chapter. There is usually a local or regional conservation, bird watcher's, or wildlife protection group, state or national park with their associated offices, museum, or similar institutions where you can get information about regional habitats and species. Also check your county or municipal planning office -- they might have a recent Natural Resources Inventory (NRI), which can be very useful.

Whatever species or habitat you have chosen, let's assume that you have some pretty good understanding of its distribution patterns, behaviors over time, and its basic ecological relationships to its environment and/or other species. The first task in this activity is to make a list all the kinds of disturbances you can think of that would upset the distribution pattern of your species or habitat. Think about the underlying relationships you discovered; think about human as well as environmental/natural disturbances; small and large; short and long-term; think about the ecological needs of a species or the dependence of a habitat on certain edaphic (soil), climatic, trophic conditions. Your list should consist of no less than five examples. Usually, however, such lists are difficult to contain!

As a next step, find out whether or not, for the habitat or species you chose, such disturbances are occurring at present. If they are not, find out whether any of these disturbances are likely. How do these disturbances affect your habitat or species? What happens to ... if...? Use common sense, your knowledge and experience, and the local resources available to you: libraries, museums, conservation groups, park rangers, local/regional newspapers, etc. Make phone calls, go visit the wildlife park, interview the park ranger, pick up literature on what alters or endangers your habitat or species. Remember, the impacts of disturbances are not always negative; some disturbances make it possible for a species to colonize or germinate in the first place, or for a habitat to host many species.

When you are finished with this part of the activity, you will have information on:

- ❑ the distribution pattern of your species/habitat;
- ❑ the ecological needs/relationships of your species/habitat;
- ❑ possible types of disturbances;
- ❑ disturbances occurring at present, or the estimated likelihood of future disturbances;
- ❑ possible impacts of the disturbance on the species/habitat distribution.

When you looked at the last two pieces of information, did you find that any disturbances occur either at the same time, or in the same place? How does that affect the distribution pattern of your species? So, as your next task, describe the disturbance regime, i.e., all the processes that cumulatively have an impact on your species/habitat. How and how quickly does the species/habitat recover from disturbance? Try to assess which of these disturbances affect the species or habitat negatively, to which of the disturbances the habitat or species is indifferent, and which of the disturbances have some positive impacts. Finally, think of ways to control or stop the disturbances with negative impacts (be realistic!), and suggest ways to enhance the species' or habitat's ability to profit more from the positive impacts or simply to maintain its ability to be resilient in the face of recurring disturbances.

Summarize the results of your research in a creative way: you may write a 3-5 page paper, or a technical report (a kind of environmental impact assessment, for example), or a shorter opinion-editorial (op-ed for short) for publication in your local newspaper. You can put together a poster including maps, photographs, statistics, and text, or make an oral presentation to your class (your instructor will let you know which formats he or she can accommodate).

3 Pattern

Answers to Activities

Activity 3.1 What Does It Take to Make a Pattern?

In Activity 3.1, students are to understand what patterns are. Words to paraphrase "pattern" may include:

- ❑ arrangement
- ❑ typical order
- ❑ sequence
- ❑ model
- ❑ standard
- ❑ design
- ❑ form
- ❑ order
- ❑ plan
- ❑ configuration
- ❑ system/atic
- ❑ repetition etc.

Examples from the infinite number of patterns with underlying spatial, temporal, and/or logical relationships include:

Spatial
- ❑ in higher latitudes temperatures are usually lower than in lower latitudes;
- ❑ a checkerboard;
- ❑ the dog was zigzagging across the path;
- ❑ the skin patterns of zebras, giraffes, leopards, etc.;

Temporal
- ❑ the four seasons in the mid-latitude (with the accompanying changes in nature);
- ❑ the sun rises and sets every day;

Logical
- ❑ the color pattern of rainbows;
- ❑ the economy is said to have a cyclic pattern of expansion and recession;

Activity 3.2 Adopt a Biome! – Adopt a Species!

Answers to this activity depend on the choices that students make regarding what biome, habitat, plant, or animal species they would like to focus on. Your assessment of their results should consider:

Completeness: Did the student cover his/her chosen topic sufficiently? Was the student able to discern a pattern/patterns?
Explanation: Did the student describe and explain the patterns in spatial, temporal, (eco)logical terms?
Resources: Did the student use a variety of resources to gather the information?
Presentation/creativity: Did the student design the presentation of results in an interesting manner?

Activity 3.3 What if...? Thinking about Patterns of Fragility

Once again, answers to this activity depend on what habitats, plant, or animal species students choose, the resources available, and the time they will spend on this project. Clearly, with the choice of a local or regional example, and the use of nearby resources, possible field visits, etc. students can become very engaged, and this is desired. Your assessment of their projects may include the following:

Completeness: Did the student cover his/her chosen topic sufficiently? Did the student follow and include the steps outlines on the *Worksheet*?
Explanation: Did the student describe and explain the patterns in spatial, temporal, (eco)logical terms? Did the student come up with a broad list of disturbances, positive and negative impacts, overlay of various disturbances? Did the student assess the tendency and severity of impacts correctly? Did the student describe appropriate remedial actions?
Resources: Did the student use a variety of resources to gather the information?
Presentation/creativity: Did the student design the presentation of results in an interesting manner?

You may also consider giving extra credit for special things students may include or do: using a GIS or mapping software, searching the World Wide Web, interviewing people who are knowledgeable about these issues, and so on.

4 Diversity

Background Information

Types of Diversity

Biological diversity, or biodiversity for short, is a concept that has become very popular and much better understood in the 1980s, significantly owing to the work of Harvard biologist Edward O. Wilson. The idea of biodiversity encompasses several kinds of "diversities," ranging over a variety of scales. We will not look at biodiversity at each scale in this module, but introduce some of the different types of diversity briefly here.

Genetic diversity

The variability within the genetic pool of one species. For example, the establishment of so-called gene banks of certain species (e.g., apples, rice, various animals) has been suggested for species that are no longer planted, sown, or otherwise occurring naturally to preserve our ability to cross-breed them with other commercial varieties.

Population diversity

The observable variation among members of a population of a given species, including stature and behavior. Humans are an obvious example.

Species diversity

The number of different species in a given habitat or biome. This is most often referred to in the context of tropical deforestation where we may unknowingly extinguish species that only existed in small niches in the rain forest and then got destroyed along with the forest.

Trophic diversity

The number of trophic levels present in an ecosystem. Trophic diversity is an indicator of the complexity of the food web. (See the section on the food web in Unit 2.)

Habitat diversity

The variability among habitats in a landscape or a region. The American Midwest can be very monotonous with regard to habitats: wheat or corn fields encompassing hundreds of hectares exhibit low habitat diversity. On the other hand, a highly fragmented landscape may be rich in habitat diversity, yet each habitat may be too small to sustain a species or assemblage of species over a long time.

The last example indicates the interrelatedness among the different types of diversity, and between diversity and other functional system characteristics like an ecosystem's stability, productivity, ability to reproduce, fragility, and resilience. It is beyond the scope of this module to investigate each of these concepts and functional relationships in detail, but it is important to note that functional characteristics of ecosystems -- like biodiversity or resilience -- are interconnected just like storage compartments of these systems by way of flows between them. While this interconnectedness, say between biodiversity and complexity of an ecosystem, is not simple and straightforward, it ultimately rests on the flows of materials, energy, and information (e.g., genetic information).

Understanding Biological Diversity at Different Geographic and Temporal Scales

The diversity of organisms that we find in an area depends on how large an area we observe and on the processes of colonization and invasion of species that created the particular degree of biological diversity within that area. Both the number of organisms and their variety expand as we broaden our view. If we expand our scope to include places beyond a particular area of focus, we see the context of our local populations in relation to their neighbors. Examination of neighboring areas can sharpen our impression of the uniqueness of our space and of the contrasts that make it different. Many reserves have been established where an ecosystem was exquisitely different from its surroundings and may also be particularly fragile or home to endemic, rare, or endangered species. The Everglades National Park is a good example, even though the sharp differences between inside and outside the Park have increased since its establishment simply because certain human activities like intensive agriculture or housing developments were not allowed inside the Park.

The geographic distribution of a population of organisms cannot be fully understood by looking at one type of organism alone. Populations of species exist in the context of many other species and within the context of the biophysical characteristics of their habitats (Ricklefs 1987). Geographical analysis of distribution patterns can guide our thinking about the diffusion processes that created the particular mix of species in a given area. This type of analysis over long spans of time (as in the study of **paleobiogeography**) provides information on what organisms diminish or disappear from local populations as new organisms evolve there or invade. Thus, a broadening of geographic scales will increase the biodiversity we find, and a broadening of temporal scales beyond the present into the past will help us understand how the biodiversity of the study area came about as a result of interactions between species.

Biotic Interactions and Biodiversity

Tracking nutrient flows is a useful way to find all of the trophic levels (positions in the food web) present in a landscape (see the graphics of the food web in the Nutrient Cycling Simulation

Activity in Unit 2). The vegetation (primary production) at a site is the foundation of all other populations living there. **Primary production**, simply defined, is the conversion of atmospheric carbon to plant biomass through the process of photosynthesis. This process requires that plants have access to resources other than CO_2 to support production. These include solar radiation, water, nutrients, and appropriate temperature.

Small spaces may not have sufficient resources to support large herbivores (animals that consume vegetation) or carnivores (animals that consume other animals). Also, animals not residing in the area may consume plant and animal matter there and then "export" the consumed nutrients by leaving to another area. Thus, the **apparent diversity** (range of organisms we observe in a space) may be lower than the **effective diversity** (range of organisms that use a space).

Invasion and Biodiversity

All of the organisms in a space moved there, or invaded, at some time in the past. We have excellent historic examples of changes that have resulted from human introductions. Some, like the potato, were intentional human imports; others, like the gypsy moth, were accidental. Other examples of "exotic" invaders into North America include the sea lamprey into the Great Lakes, the zebra mussel in the Mississippi Basin and now beyond, kudzu in the southeastern United States, and Russian thistle (tumble weed) in the Great Plains (Culotta 1991).

The Africanized Honey Bee

Few invasions are as well documented as the invasion of the Africanized honey bee (see the animated slide show ***AFHBEES.FLI***). The African honey bee was introduced into Brazil in 1957 (Rowell *et al.* 1992). It aggressively took over hives and queens of the European bee, another intentionally introduced bee, and spread rapidly. Early speculations were that the resultant spreading and mixing would dilute the African genes and that aggression would be diminished in the altered genetic stock. Efforts to halt the northward advance have been unsuccessful, and the Africanized bee spread into Texas in 1991. The genetic material on the frontier of this invasion is over 90% African, contrary to the genetic dilution hypothesis (Makela 1994).

Entomologists expect that the northward migration of the Africanized bee will be halted by climate because the metabolic processes of the African bee evolved in a warmer climate than those of the European bee species which is the species predominantly found in the Americas (Taylor and Spivak 1984; Southwick *et al.* 1990). Some speculate that the northward advance of the Africanized honey bee will be halted at midcontinent in the range of about 40° north latitude; it remains to be seen if that hypothesis is valid. Questions about the species' adaptability to cooler conditions and about climatic changes that may enlarge the suitable habitat for the Africanized bee remain unanswered.

The question of how rapidly genetic adaptation can take place is particularly interesting. Will the mixing of the two bee varieties at the northern edge of the invasion favor the selection of European bee genes that facilitate better metabolic adaptation to cold climates? Also questionable is the ability of the Africanized bee to resist parasites and viral infections that now plague the European bee populations in North America. The aggressive bee is now invading a weakened resident population. Finally, an increase in greenhouse gases thought to lead to a warming of our climate may not only expand the northern range of the Africanized bee, it may also weaken the resident European bees further, thereby facilitating the invasion of the Africanized bees.

Resistance Barriers, Corridors, and Staggered Invasion

Invasions of organisms like the Africanized bee create the diversity of organisms in a place. It is not likely that all occupants of a space invaded at the same time. Analysis of fossil plant materials confirms the staggered invasions of plants through time. In the period from 14,000 to 6,000 years before the present, glaciers melted, exposing vast areas of glacial debris that were free of plant and animal life (see the glacial retreat animated slide show ***ICEAGEWI.FLC***). The suite of plants and animals that persisted beyond the margins of the ice had the best chance for invading the territory uncovered by the retreating ice sheet. They differed considerably in their abilities to disperse into new spaces and in their tolerances of newly available environments. Later arriving plants had to pass through a **resistance barrier** of already occupied spaces (see the migration animated slide shows ***FINCHES.FLI***, ***GRASSINV.FLI***, and ***TREEINV.FLI***).

At the peak extent of glacial ice, the southern and central Plains were dominated by short grasses (e.g., blue grama, black grama, sideoats grama, buffalo grass) that probably invaded from the Southwestern deserts at an earlier date (see the *Appendix* for an additional reading that includes drawings and maps of these and the following grasses). Tall grasses (e.g., big and little bluestem, Indiangrass, and switchgrass) dominated the Florida Peninsula and probably were abundant in areas of the Gulf of Mexico, which was exposed when sea level was low during the last glacial maximum (about 18,000 years ago). In the Great Basin, west of the Rocky Mountains, cool-season grasses (western wheatgrass, bluebunch wheatgrass, needle-and-thread, and green needlegrass) were present and dominated some parts of the landscape.

The extensive erosion and deposition along the Mississippi Valley provided a corridor for the Southeastern tallgrasses to invade the Midwestern Plains and move up the Arkansas and Missouri tributaries into the Great Plains. The cool-season grasses found their way into the plains through gaps in the Rocky Mountains. A suite of disturbances, including erosion and deposition along valley bottoms and hills, movement of sand dunes by wind, trampling and wallowing by bison, provided opportunities for the aggressive invaders to capture territory formerly vegetated by the warm-season shortgrasses and spruce and pines that found the Northern Plains increasingly inhospitable as the glaciers melted (see the animated slide show ***GRASSINV.FLI***).

Many of the plants that colonized the Northeast in the wake of the receding glacier front were deciduous trees that ranged from the lower Mississippi Valley to the Atlantic Coastal Plain during the last glacial maximum. Others were spruce, pines, and hemlock that spread from the Ohio River Basin and Mid-Atlantic coastal plain. Birches were probably confined to the exposed continental shelf of the Atlantic and in Alaska at the glacial maximum, spreading from both areas to quickly colonize the exposed glacial landscapes (see the ***TREEINV.FLI*** slide show).

These changing patterns of abundance for prevalent plant types during past global climate change events exemplify a process that is common to all species. In addition to the purposeful and inadvertent introductions of species, humans have significantly altered the process by creating avenues for more rapid migration or by creating barriers to movement (e.g., the annual plowing of extensive areas has produced significant barriers to the dispersal of perennial plants and animals that depend on the perennial plants).

4 Diversity

Instructor's Guide to Activities

Goal

The primary goal of the activity in Unit 4 is to help students visualize how the diversity of organisms of places evolves and how it differs from place to place. A secondary goal is for students to learn how to perform simple sensitivity experiments that test (a) the effects of human intrusion into the dispersal process by the erection of barriers to movement, and (b) the effects of starting conditions on subsequent species patterns.

Learning Outcomes

After completing the activities associated with this unit, students should be able to:

- work with a spreadsheet
- understand the principles behind and the usefulness of simulations
- describe the processes, patterns, and outcomes of species dispersal and ecosystem disturbance
- write a rounded, well-balanced statement on the impacts of human interactions with biomes

Choice of Activities

Unit 4 is accompanied by only one, lengthy activity encompassing several individual tasks. After manipulating the spreadsheet, students are asked to answer a number of questions. You may choose to assign only selected questions.

Suggested Readings

The following readings are recommended to accompany the activities for this unit. Choose those readings most appropriate for the activities you select and those most adequate for the skill level of your students.

- Unit 4, *Background Information* (provided)
- Relevant sections on species dispersal, biodiversity, and disturbances from the course reading found in the *Appendix* (provided)
- Other papers relevant to the topic of this unit at the instructor's discretion

Activity 4 Dispersal and Diversity Simulation Model

Goal

Students enhance their ability to work with spreadsheets and simulation models by executing several simple sensitivity experiments. These experiments allow students to examine the effects of various species dispersal patterns and ecosystem disturbances, and to abstract from the world of models to real processes in their environment.

Skills

✔ navigating and using a spreadsheet
✔ critical thinking
✔ working in pairs or teams
✔ oral or written presentation of simulation results
✔ applying abstract model insights to real-world examples

Material Requirements

A copy of the spreadsheet database ***DIVERSE3.wb1*** (provided on disk)
A spreadsheet software package, preferably *Quattro Pro 5.0 for Windows* or *Excel 4.0*
A copy of the slide shows ***FINCHES.FLI, GRASSINV.FLI, TREEINV.FLI, ICEAGEWI.FLC***, and ***AFHBEES.FLI*** with ***ANIPLAY.EXE*** (provided on disk)
Student Worksheet 4 (provided)
Suggested readings (some provided)

Time Requirements

1 full lab session for the computer simulation exercises
Out-of-class time to write a summary paper (alternatively, 1 hour maximum for in-class presentation of results)

Task

The spreadsheet lay-out and functioning are explained in detail on the *Student Worksheet*, followed by instructions of how to simulate different types of disturbances. If your class is large, try running the simulation exercises in pairs or small groups. Each student should have a hands-on experience on the computer, but team work and discussion can facilitate the understanding of the simulation model and results. The outcomes of their discussions can be presented in in-class presentations by each group, or in team-composed or individual papers, depending on your preferences, course goals, time availability, and availability of teaching assistance.

DIVERSE3.wb1 is laid out in two sections (for further explanations see the *Student Worksheet*): the first section extends from row 2 to 99, and the second section extends from row 101 to 198. The second section is simply a copy of the first and is added so that students can manipulate the model in the first section while preserving a copy of the original as a backup below. Students should be encouraged to try out different disturbances and barrier types to see the effects on organism dispersal and resulting species diversity. They should realize that the dispersal is limited to adjacent cells; thus an absolute barrier one cell wide will block dispersal. There will be no single, correct outcome. Rather, the outcomes are the product of a neighborhood function (all adjacent cells can receive dispersed organisms) and random chance (every recalculation forces changes in 13 * 4 random numbers). The possible futures from this operation are many!

The model should evoke discussion about what can act as barriers for organism dispersal. For plants, cultivation is a major barrier. Railroads, rivers, and roads are corridors that accelerate the dispersal of some organisms. Students should try to explain how any disturbance they think of acts as a barrier and/or corridor for species.

Students may wonder about long-distance dispersals that are not included in this model. They do take place, but have a very low probability of occurrence, except among plants, animals, or disease organisms that use animals as vectors. In fact, disease organisms may more easily become established at some distance than nearby because of the lack of immunity in areas isolated from the disease organism. Should this fit into your course schedule, an interesting section on global change and vector-born diseases could follow here. A starting point for discussion may be the following journal article (but the literature on this subject is huge and growing):

> Martensen, W.J.M. 1995. Climate change and vector-borne disease: A global modeling perspective. *Global Environmental Change* 5, 3: 195-209.

Note also that as part of the CCG2 project "Developing Active Learning Modules on the Human Dimensions of Global Change," a module is being developed in 1996/97 that explicitly deals with global change and human health impacts.

4 Diversity

Student Worksheet 4: Dispersal and Diversity Simulation Model

Preparation

Before you begin working on the dispersal and diversity simulation model, you should have read the *Background Information* of Unit 4. Your instructor may have assigned additional readings on diversity, dispersal, and disturbance. All of these will help your understanding of this activity.

Purpose of this Activity

This activity is intended to show that diversity is the result of many individual events of dispersal. The dispersal process requires gene pools in one place with connections to other places. When such connections are destroyed along with the local diversity, diversity is regained only very slowly. The simplified model we will use here shows how corridors or barriers constructed by humans can alter the biodiversity of places. We will manipulate the environmental factors that govern spatial change of multiple organisms vying for the same spaces and examine how the changed factors affect the dispersal processes of species.

Introduction

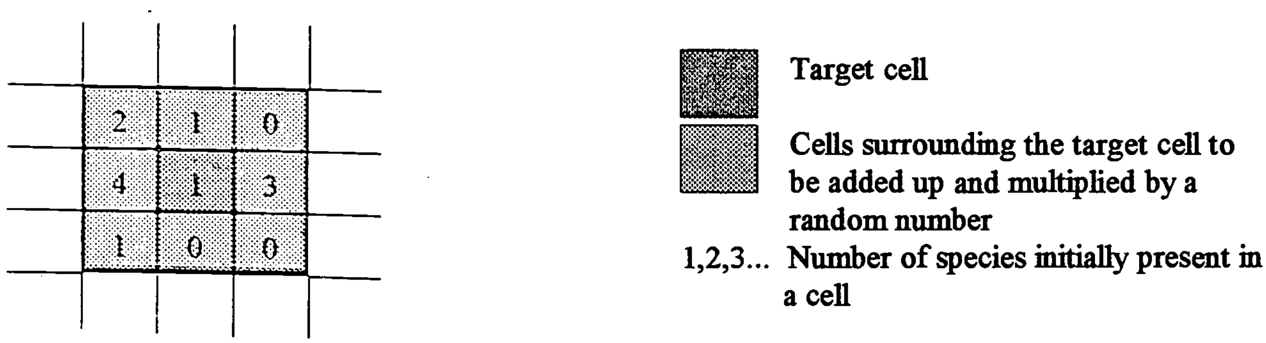
Let's use an example to explain what we will look at in this activity. Imagine an individual farmer who plows 40 acres annually and thereby creates a small barrier to perennial plants that migrate across the field. If many adjacent farmers do this or if the field size is even larger, you have a situation like that of Midwestern farmers in the U.S. (This is common, however, in many parts of the US as well as in countless other countries): the aggregate impact of many human decisions to cultivate land has created vast barriers to plant dispersal. Again, in many Midwestern counties, 95% of the land is now cultivated annually. This severely isolates the tiny remnants of pre-cultivation vegetation from the exchange of genetic materials that occurred prior to intensive agriculture. Other land cover changes like the creation of long reservoirs can be just as devastating to the migration fish and terrestrial animals.

The impact of land use changes on genetic and species diversity is the central theme of this activity. Understanding these impacts through simulations requires that we model the spatial distribution of species, their spatial behavior (e.g., how fast they can spread), and the occurrence of barriers or corridors that will alter this spatial behavior. So, modeling the spatial behavior of individual species allows us to articulate the spatial outcomes of this behavior.

The ***DIVERSE3.wb1*** simulation model is a relatively simple method to visualize how the diversity of organisms in one place is a result of interactions with adjacent places and how biodiversity is affected by habitat constraints and chance.

A site's adjacent places are those most likely to contribute new genetic material. Habitat constraints (like rooting depth or disturbance frequency) make the site more suitable to some organisms than to others. Chance governs the combined probabilities of the timing of an opportunity for a new organism to enter and the readiness of a plant or animal to occupy that newly available space. The model we use here intentionally simplifies reality in order to illustrate the principles of chance, spatial variability of site characteristics, and the varied genetic contexts of each potential invasion site at each time step. The model does not include a so-called local "extinction function" (a separate programmed step that removes some of the population). Such an extinction function would reduce the diversity of spaces and allow subsequent new immigrants. The model does, however, have a "random chance function," which allows the removal of some species from the competition for space. It does that by adding up the species in the eight spaces (cells) surrounding a central cell (the "target cell") and multiplying that number by a randomly chosen number. If the sum of the species in the cells surrounding a target cell times the random number totals less than 1 (rounded up from 0.5), then the species becomes extinct in the target cell in that step (see Figure 2 below and the ***DIVERSE3.WB1*** sample spreadsheet on the next page).

Figure 2: Excerpt of the DIVERSE3.wb1 model



Instructions

① ***Opening the Spreadsheet***: Use a spreadsheet program such as *Quattro Pro 5.0 for Windows* to open the spreadsheet notebook ***DIVERSE3.WB1*** or import the file into a Mac-program like *Excel 4.0.*

② *Important Spreadsheet Terminology*: Before we run the simulation, let's familiarize ourselves with this particular spreadsheet. If you do not recall the general terms used to describe a spreadsheet -- row, column, cell, cell address, cell entry, and cell formula -- consult the explanation on the ***NUTCY4*** worksheet of Unit 2. In addition to those terms, we will use several new ones here; grid and block. The term *grid* is any space segmented into smaller rectangular pieces. Grids are commonly laid over landscapes as an aid in systematically collecting data. In our case, we would use the grid to count the members of a particular species per grid cell. The number of species members is then entered into the spreadsheet. A *block*, on the other hand, refers to a portion of a spreadsheet: when you mark a portion of a spreadsheet that encompasses parts of several rows and of several columns, e.g., a block spanning from G2 - G8 (rows) and from G2 - K2 (columns) you are marking a 7 by 7 cell block. In a spreadsheet you would use a block to represent a grid. Thus, you may think of the spreadsheet blocks for a particular species as a map that shows how frequently a particular species is found in different portions of the modeled landscape.

③ *The Spreadsheet Layout*: The ***DIVERSE3.wb1*** spreadsheet is laid out vertically as 5 blocks of 5 columns each (separated by small gray-shaded columns) that represent different time periods (Time1, Time2, etc.) for a 5 by 5 cell grid. Horizontally, the spreadsheet is divided into a top portion that shows blocks of numbers of real, potential, and unsuccessful species, and a lower portion with a five-row block each for Species1 through 13. In the upper left corner of the spreadsheet you see a 5 by 5 cell grid of the site that we will focus on (the shaded block); it contains the constraints of the model area. We refer to this block from here on as the "habitat types block." The numbers in this block tell the maximum number of species that can live in a grid cell (hence a "constraint"). The simulation model is illustrated in the first 98 rows and tracks 13 species. Below row 100 is a duplication of the first 98 rows. Use the space in rows 101 to 198 for experimentation; rows 22-99 are a backup, should you need to copy beginning values of formulae to start over. Finally, beginning in cell AK23, column AK contains random numbers -- representing the model's random chance function -- that are recalculated each time the spreadsheet goes through a recalculation cycle.

Let's take a closer look at the top portion of the spreadsheet which is in bold type (see print-out on the spreadsheet, *Supporting Material 4,* if you don't follow the explanations on the computer screen). The top three block rows are accounts of what happens in the 13 species blocks below. The first row, **POTENTIAL Species#,** shows the number of species that have dispersed to that cell. The second row of blocks, **REAL Species#,** is the POTENTIAL Species# minus the limit placed by the **Habitat types** block on the number of species the habitat is likely to contain. This is a gross simplification of reality. A place with 10 habitat types able to hold 10 plant species each, could hold a maximum of 100 species. That level of diversity may be unstable and thus has a very low likelihood of occurrence. In this model the number of species possible is 1 per habitat type. The third row of blocks contains the **UNSUCCESSFUL Species#,** which is the POTENTIAL Species# minus the REAL Species#. The model does not keep track of which of the species are the unsuccessful ones. The REAL species# block is the one that tracks the diversity of the spaces.

Now let's look at the lower portion of the spreadsheet. The processes that are at work in the dispersal of multiple organisms take place in the 5 by 5 row blocks starting with row 22 for Species1 and continuing through Species13. Beginning patterns for each species are supplied in the Time1 block. The formula that governs how species are spread starts with cell E21 and is a relational formula (in which the mathematical procedure, i.e., the type of equation, stays the same, but depending on where in the spreadsheet you are, the cells that enter into the equation change). The relational formula is copied to each cell of each block for Time2 through Time5.

④ ***Simulation Inputs***: So now let's see what we need to run the simulation. Recall that in order to understand dispersal and diversity, you need to know three basic elements (of course, this is the simplified world of the model): the species we begin with, how they are disturbed, and what the random chance function is. The ***DIVERSE3.wb1*** model uses exactly these three types of inputs:

A beginning distribution map for each species being considered

(the 5 column block starting with the column labeled Time1). Our example uses 13 different species with a fixed starting condition (only 2 of which could be shown in the screen image print-out included here). In the example, the starting condition maps for Species1 and Species2 assume that a major disturbance has removed all organisms from the center 9 cells. The numbers 1 or 0 indicate the presence or absence of the species in that space at Time1. What you see on theat print-out is that Species1 and Species2 start to invade the space, but chance outcomes cause their local extinction.

A map of habitat/disturbance regimes

(habitat types in the upper left corner). This map differentiates the resources and hazards of the study space. The map has 25 cells with different niche opportunities that can support from 1 to 9 species at a time. In this abstraction of reality the number of species is limited by the diversity of local resources and hazards.

A random number that can vary the outcomes of the model

This part of the model recognizes the randomness in nature. If we started any process of dispersal over again with all environmental traits constant, the outcomes would be slightly different because of the complexities of multiple conditional probabilities. At each time period, the random number is used to define the probability that a species invaded a cell from any of the surrounding 8 cells. This implementation of the random chance process uses one random number per row to govern the outcome of all spaces for a time period (column AK). Obviously, this part of the simulation can have much more complexity by providing a separate random probability for each species to invade each cell. In the real world most invasions come from immediately adjacent spaces, but distant spaces have some small chance of supplying invaders. In this model the spatial linkage is kept simple to allow the model to minimize computer memory requirements.

Move to the bottom half of the spreadsheet ***DIVERSE3.wb1*** by using the page down key. The TEST portion of the page is a copy of the top 98 rows and can be altered for experimentation.

The model inputs can be altered by the user in three ways without altering the equations.

Change of the starting patterns

The starting patterns of individual species can be changed by changing the 1's and 0's of species in the Time1 column.

Change of the random chance elements

Place the cursor on a blank cell and press the delete key to change the random number that governs the chance element for invasions. This action causes the entire spreadsheet to go through a recalculation cycle. The random number that affects each individual species invasion process changes, altering all of the species outcomes and the diversity (REAL Species #) maps.

Change of the habitat constraints

By changing the habitat type map cells, you can alter the constraints on the number of species that can be accommodated in a space. These numbers should be from 0 to 13 (the number of species used in this model).

⑤ ***Running the Simulations***: Following the instructions below, use the model and the various change options to explore the following questions about the development of diversity. Analyze the results and write down your answers on an extra sheet of paper.

1. Examine the series of Species# maps. How does diversity of the 9 center cells change through time?

2. Change the random number in the method described above until you get a high number of UNSUCCESSFUL Species# recorded in Time5. You are essentially rolling five dice 13 times each time the spreadsheet recalculates. It may take many tries to get extremely high or low numbers of UNSUCCESSFUL Species. Print or record the patterns of the series of Species# maps. What is the difference in effect of high and low probabilities of invasions and resulting diversity patterns?

3. Change all beginning maps (Time1, columns G through K) for Species1 to Species13 maps to have only 1's in the 2 left columns (G and H) and 0's in the 3 right columns (I, J, K). What is the effect on the development of diversity if you start the species invasions from the same side?

4. Change the middle column of habitat types (C104 to C108) to accommodate no species at a time (only 0's). By doing this, you are constructing an absolute barrier like a long reservoir that is too wide for terrestrial organisms to cross. What is the effect of this absolute barrier on the development of diversity on the right side of the map?

5. Change two cells (cells C105 and C107) in the middle column of habitat types (which, after the last run, should have only zeros) to accommodate one species at a time. This changes the absolute barrier to a high-resistance barrier. The cells changed to 1's are limited-capacity bridges. What is the effect of this high resistance barrier on the development of diversity on the right side of the map?

6. Change all of the middle column of habitat types (C104 to C108) to accommodate one species at a time. What is the effect of the low-resistance barrier you have constructed on the development of diversity on the right side of the map?

7. This experiment asks you to test accelerated dispersal. Human environmental changes often create corridors of high-disturbance frequency that speed the migration of organisms. For example, a road construction corridor that is stripped of vegetation, if not seeded promptly, provides excellent opportunities for species to move along that corridor. Similarly a river that remains flooded for several weeks kills much of the floodplain vegetation, leaving an extensive corridor for plant dispersal. Change all of the middle row of habitat types (A106 to E106) to accommodate all 13 species at a time. What is the effect of the no-resistance corridor on the development of diversity on the right side of the map?

8. For each of the different types of interference with dispersal you have just modeled, think of some examples of human actions that would have the same effect.

The answers to your questions should either be synthesized in a summary paper or presented in a useful way to the class. Your instructor will let you know which formats s/he can accommodate.

4 Diversity

Answers to Activity 4

Dispersal and Diversity Simulation Model

Students may be expected to make the following observations in the simulations:

1. Many species do not persevere over the course of the simulated time (Species1-3, 6-7, 10-12). Only few proliferate, some faster (Species4, 5, 8) than others (Species9, 13). By Time5, diversity in the inner 9 cells is generally higher compared to the diversity on the fringes, reflecting the maximum interaction between species inside the grid. Note that this particular outcome is the result of the limit of the grid. Unless there are distinct barriers around an area, a natural ecosystem -- however defined -- does interact with ecosystems beyond its defined boundaries.

2. The result of having a high number of unsuccessful species is that species diversity goes down. Individual species display more pointed success or failure patterns, i.e., they quickly are lost or they quickly proliferate. Invasion by the successful species is more pronounced.

3. When all species invade from one side, species diversity develops fairly equally (it is almost symmetrical) on either side of the central column (AG) by Time5. The central column hosts only one species, because of the habitat constraints for this column. Few species are entirely unsuccessful in this run and most others can be found in >50% of the grid cells at Time5.

4. If this simulation is run with the left two columns having only 1's and the right two columns only 0's, diversity will be almost symmetrical around the absolute barrier by Time5. Interestingly in this case, the diversity of the left side of the barrier remains stable from Time1 through Time5. Only on the right hand side does it increase. If, on the other hand, this simulation is run with the original species distribution (copied from the top rows [22-99] into the lower test portion of the model [rows 122-199]), species diversity declines from Time1 through Time5 because of the limited exchange across the barrier. Several species are lost entirely.

5. No matter what the initial species distribution on either side of the high-resistance barrier, diversity can vary quite broadly for this type of model simulation (run several recalculation cycles to see this). The places where species can cross over always host one species at Time5 (according to the habitat constraint) and the cells before and after the cross-over are hardly ever occupied by

less than one species. Generally, species diversity in those 4 cells is rather high, and is usually not lower in the inner 9 cells than on the outer ring of the grid.

6. The situation is very similar to that described in point 4. above; however, species diversity is higher overall because there is at least some exchange across the low-resistance barrier.

7. Note the very low number of unsuccessful species in this case! If the no-resistance simulation is run with the left two columns having only 1's and the right two columns with only 0's, diversity will usually be highest in the center of the grid. The inner ring has higher diversity values than the outer ring. If, on the other hand, this simulation is run with the original species distributions (copied from the top rows [22-99] into the lower test portion of the model [rows 122-199]), species diversity is generally lower than in the above-described case and is much more homogenous across the grid. Still the central cell may be the one cell with the highest species diversity.

8. Examples of human interference with species dispersal and diversity include:

Table 3: Computer Simulations and Corresponding Real-World Examples of Human Interference with Ecosystems

Type of Simulation	Examples of Human Interference
Change of random numbers to get extreme numbers of unsuccessful species	❑ repeated destruction of parts of habitats ❑ total destruction of an entire habitat ❑ paving an area ❑ water-logging a previously dry land area ❑ channeling a stream, eradicating wetland species that grew there before the channeling ❑ filling in wetlands
Change of beginning maps to the 1-1-0-0-0 pattern (dispersal from one side)	❑ planting trees in one area of an otherwise bare plot ❑ planting dune grass to allow dunes to form and persist in the face of erosion
Change of the center column to all 0's (absolute dispersal barrier)	❑ erecting a wall ❑ building a canal ❑ constructing a wide highway

Type of Simulation	**Examples of Human Interference**
Change of the center column to 0-1-0-1-0 (high-resistance barrier)	❑ building a road with frog fences; frogs are collected and brought across the road occasionally ❑ plowing fields; occasionally there is an unplowed edge along which species can disperse
Change of the center column to all 1's (low-resistance barrier)	❑ allowing the area underneath power lines to grow over, but cutting it occasionally so that some species won't be able to disperse ❑ installing a gas pipeline
Change of the center column to all 13's (no resistance, corridor)	❑ intentionally sowing species in a plot ❑ any freshly opened soil (after a clear-cut; the sides of a road after construction, a plot after burning, etc.)

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Glossary of Terms

This glossary contains terms related to biogeography and the human dimensions of global change. They appear frequently in the Background Information of the four units. Terms that appear in bold in the right-hand column also occur as separate glossary entries.

Africanized honeybee	Descendants of bees imported into Brazil from Africa in 1957. Through dispersal and mixing with honeybees originally imported from Europe, the offspring remain over 90% dominated by African genetic materials.
apparent diversity	Range of organisms observed in a space.
biodiversity	Short for biological diversity. A broad term indicating the variety in organisms, characteristics of a population, species, genetic material, and habitats.
biogeography	A subfield of geography that tries to explain why organisms occur the way they do, where they do. For that purpose, biogeography produces inventories of organisms, investigates spatial distribution patterns of organisms, and studies the interactions among organisms and between organisms and their environment.
biome	A large region that exhibits similar plant types, animals, soils, and climate.
biosphere	The totality of all regions on the earth that support life and are affected by life, including parts of the atmosphere (air), hydrosphere (water), and the lithosphere (solid portions of the earth, rocks).
boundary conditions	In order to study an **ecosystem**, a researcher must delimit the system spatially, temporarily, and often structurally and functionally. These limits describe the boundary conditions of the system and the study.
C3-plants	The first product in the sequence of biochemical reactions involved in the **photosynthesis** of such plants has three carbon atoms. Examples include wheat, rice, and soybeans. C3-plants respond readily to an increase in atmospheric CO_2 with increased productivity (compare **C4-plants**).

C4-plants — The first product in the sequence of biochemical reactions involved in the **photosynthesis** of such plants has four carbon atoms. Examples include maize (corn), sorghum, millet, and sugarcane. C4-plants are likely to be less efficient photosynthesizers in a carbon-enriched atmosphere (compare **C3-plants**).

carnivore — Meat eater.

carrion eater — Animal, like the vulture, that consumes dead animals it did not kill.

causes of global change — See **human driving forces**.

cell — Where rows and **columns** intersect in a **spreadsheet**, they create a cell. Each cell is identified by a unique **cell address**; it contains data (a **cell entry**) or a **cell formula**.

cell address — The unique way to identify a **cell**, consisting of a letter (indicating the **column**) and a number (indicating the **row**).

cell entry — The **data** found in a **cell**.

cell formula — A mathematical procedure or calculation entered into a **cell**.

classification — A systematic method of placing objects (e.g., plants, animals) into groups/classes based on a set of similarities (origin, genetic make-up, population characteristic, etc.). The aim of a classification is simplification.

climate change — A change in the average, long-term climate conditions characteristic of a region or the earth. (See also **global warming**.)

column — The vertical partition in a **spreadsheet**.

cool-season plants — Plants that use the **C3** photosynthetic processes, which optimize the conversion of atmospheric carbon dioxide to plant carbon at about 20° C. (See **C3-plants**.)

corridor — An area particularly conducive to the dispersal or spread of organisms.

data — **Observations** made of a phenomenon. The fundamental inputs into scientific analysis.

disease organisms	Bacteria and viruses that may kill or injure the host they depend upon for life and dispersal.
ecology	The study of the interactions among species, and between species and their environment. The term derives from the Greek word *oikos* which means house or home.
ecosystem	All living organisms together with the physical environment in which they live and which they affect through a complex set of mutual interactions.
effective diversity	The range in types of organisms that use a space.
energy transfer	The moving of energy from one storage unit to another. In the process of feeding, an animal transfers energy (measurable in calories) from the plant to its body.
field capacity	The amount of water that soils can hold against the pull of gravity and that can be used by plants.
food chain (food web)	A metaphor for the hierarchical interrelationship among organisms in an **ecosystem** that describes the uptake and **transfer of mass and energy** (nutrients) from **primary producers**, to **herbivores**, to **carnivores**, **omnivores**, and scavengers/**carrion eaters**, to decomposers which close the nutrient cycle.
geographic distribution	The differential occurrence of a phenomenon across space. (See also **geographic pattern**.)
geographic pattern	The way in which something happens, moves, develops, or is arranged in space. Many phenomena display typical patterns. For example, rivers in lowlands typically become wide and often meander, creating typical landforms that are associated with specific types of vegetation (e.g., wetland or river bank habitats). (See also **variability**.)
global warming	A change in global average temperatures as a result of an accumulation of heat-trapping gases in the atmosphere (see also **climate change**.)
grain	Seeds of domesticated grasses, used to feed livestock or humans.
headings	Titles or labels for columns in a **spreadsheet**.

herbivore Plant eater.

human dimensions of global change The complex set of human causes, impacts, and responses to global environmental change. (See also **human driving forces, climate change, global warming, impacts of global change, responses to global change.**)

human driving forces Large societal changes that are thought to be causally linked to changes in the global environment. Human driving forces are commonly identified as (1) population, (2) technology, (3) economy, and (4) human values, beliefs, and institutions.

impacts of global change The effects of **global (climatic) changes** on humans or the environment.

isarithmic lines Lines of equal value. An example is in a contour line that represents equal elevation on a topographic map.

limiting factor A characteristic of the environment (e.g., light, water availability, soil type, or abundance of predators) that restrict the growth or abundance of a plant or animal species.

mass transfer The moving of mass from one storage unit to another. In the process of soil erosion, masses of soil are moved from a topographically higher point downslope.

mixing The process of combining and thereby diversifying the genetic characteristics of members of species that are able to interbreed.

observation What we discern our senses tell us about our surroundings. The principle process from which we derive **data** for scientific research.

omnivore An animal, (e.g., a bear, crow, and some rodents), that eats both plants and animals.

paleobiogeography The study of previous animal and plant populations and their spatial patterns and dynamics in geologic time.

parasite An organism that provides no benefit for the host animal or plant and gains no benefit from its death. Examples include fleas, lice, schistosomes, and parasitic plants (e.g., orchid, mistletoe).

permafrost	The state of permanently frozen ground (i.e., for the greater part of the year).
photosynthesis	The process by which plants fix carbon from atmospheric carbon dioxide into plant organic matter and release oxygen and water vapor back into the atmosphere.
population	A group of organisms coexisting at the same time in the same place and capable of interbreeding.
production	The conversion of geophysical resources (water, nutrients, CO_2, light) into biomass (primary production) (see **primary producers**), and of that biomass into biomass at higher **trophic levels**.
primary producers	Plants that use sunlight to fix atmospheric carbon into organic matter through **photosynthesis**.
resistance barrier	An obstacle to the dispersal of organisms.
respiration	The exchange of gasses between the atmosphere and an organism.
responses to global change	All forms of haphazard or intentional human adaptations to a changed environment.
row	The horizontal partition in a **spreadsheet**.
sampling (design)	The technique of selecting a subset of members of a larger population when it is (as is commonly the case) impossible to study the entire population. Depending on the purpose of the study (e.g., to get a sample that represents the entire population), a researcher chooses individual members in a particular fashion (the sampling design).
selva	A **biome** of wet tropical forests composed of a wide variety of broad leaf, evergreen trees and animals adapted to the climatic and vegetation setting.
sensitivity analysis	A method that tests the responsiveness (sensitivity) of a system to changes in one variable (an element that varies) of the system.
species	A category of closely related and similar organisms. More narrowly defined, a **population** of individuals capable of interbreeding but not of breeding with members of another species.

spreadsheet — A computerized table. The spreadsheet appears as a grid made up of **columns** and **rows** that contain data or formulas.

steppe — A **biome** dominated by grasses, grazers adapted to open landscapes, and a semi-arid climate.

symbiosis — The mutually beneficial interrelationship (symbiotic interaction) of two or more organisms that is essential to the organisms' survival and reproduction.

swidden agriculture — The practice of clearing small plots of forested land for growing a mixed planting of crops, followed by a long period of abandonment.

tillering — The vegetative reproduction and replication of a plant by increasing the number of emergent reproductive and vegetal shoots.

tool bar — The row of symbols, each indicating a function of the computer software, near the top of the computer screen.

trophic levels — The position of an organisms in the **food chain** (or **food web**).

tundra — A **biome** underlain by permanently frozen ground which prevents nutrient leaching; the tundra vegetation consists of low perennial herbs, shrubs, lichens, and grasses adapted to a very short growing season and tolerant of wet soils.

variability — The tendency to vary or fluctuate around an average or expected value, or around a specific average pattern.

warm season plants — Plants that use the **C4** photosynthetic processes, which optimizes the conversion of atmospheric carbon dioxide to plant carbon at about 35° C (see **C4-plants**).

yield — A generated or earned output (result, profit, or production outcome).

Supporting Materials

Technical Note on Computer Display of Visuals

The animated slide shows are designed to run on the animator player program *ANIPLAY.EXE* (provided on the enclosed disks). It is a DOS based program, although some Windows-based programs recognize the two formats generated by Autodesk Animator programs. Other shareware programs are available to view these graphics. *ANIPLAY* can be run in multiple screen modes. The materials used here operate in two screen modes. These area as follows:

File	Screen Size
AFHBEES.FLI	320 x 200
FINCHES.FLI	320 x 200
FOODWEB.FLC	640 x 480
GRASSINV.FLI	320 x 200
ICEAGEWI.FLC	320 x 200
TREEINV.FLI	320 x 200

Screen size can be changed under the file menu.

The disk with the *ANIPLAY.EXE* file also contains a number of video drivers in a **\RESOURCES** subdirectory. This subdirectory and its files should be copied onto a **\RESOURCES** subdirectory within the directory to which you copy the *ANIPLAY.EXE* file and the individual slide show files.

Caution: *ANIPLAY.EXE* may have difficulty with some computers which use 386 extended memory managers. If you encounter this problem, edit your *CONFIG.SYS* file, putting the word **rem** at the beginning of the line which refers to the 386 manager. This remark notation should be removed following use.

The menu blocks can be removed form the screen by clicking the right mouse button with the cursor outside of the menu box. Frames can be advanced with the right cursor button. The menu blocks can be restored on the screen by clicking the right mouse button. The movie can be played continuously by clicking the pointer on the >> symbols in the menu box.

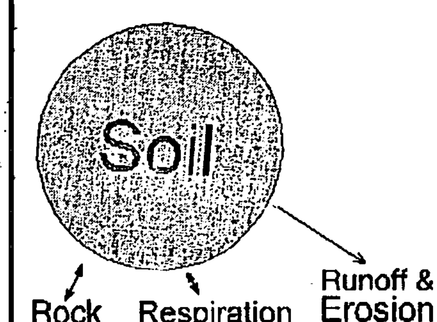
Print-Outs of Food Web Slide Show

The following pages contain print-outs of each frame from the food web slide-show. They may be photocopied or reproduced as overhead projections.

The Food Web
Nutrient Cycle
Pathways
And
Trophic Levels

All Nutrients
Originated
From
Weathered
Rock.

All nutrient transfers
were initially
chemical or
mechanical
processes.



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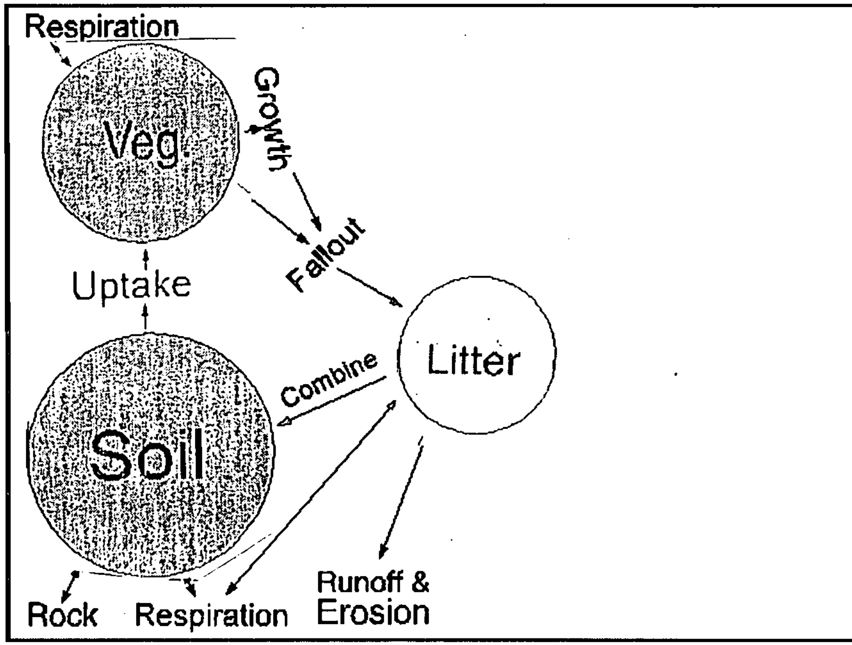
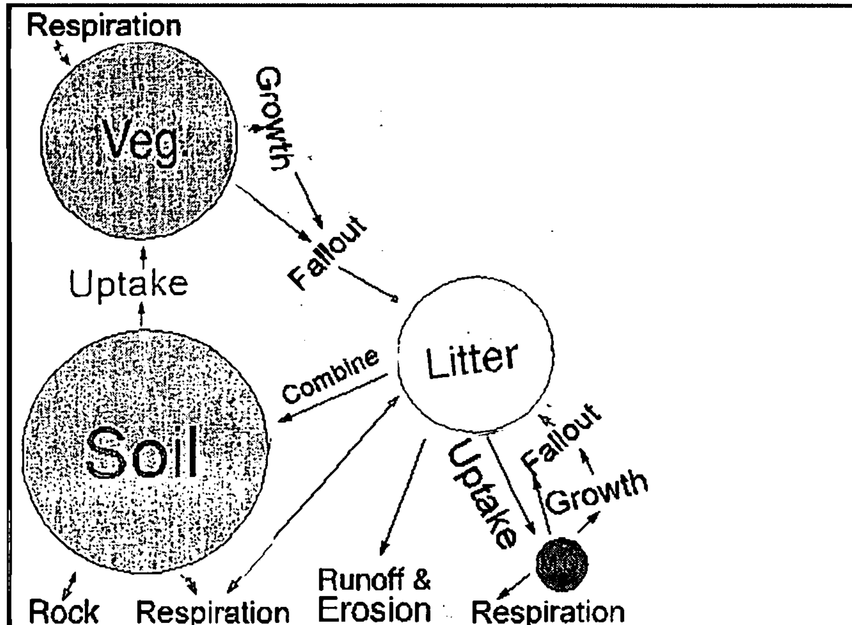
Photosynthesizing organisms evolved to create a biogeochemical cycle.



Micro-organism additions to the biogeochemical cycle accelerated litter decomposition



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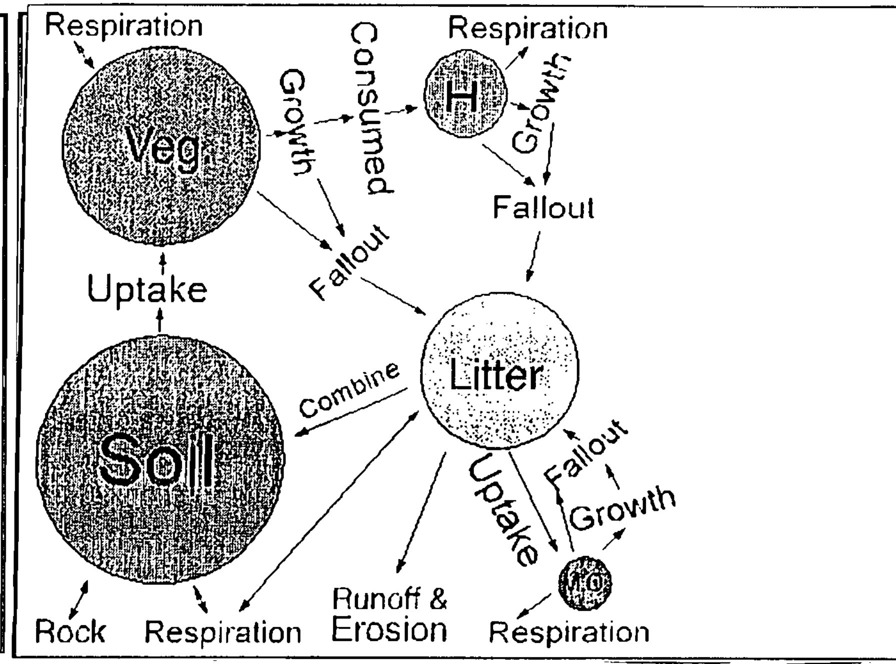
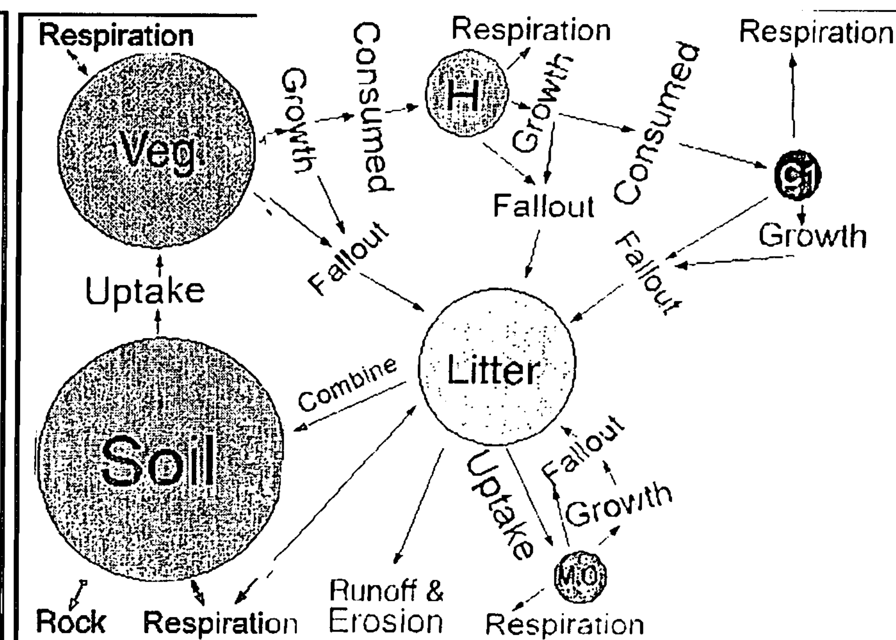
Herbivores evolved to capture standing vegetation



Carnivores evolved to consume nutrients in herbivores



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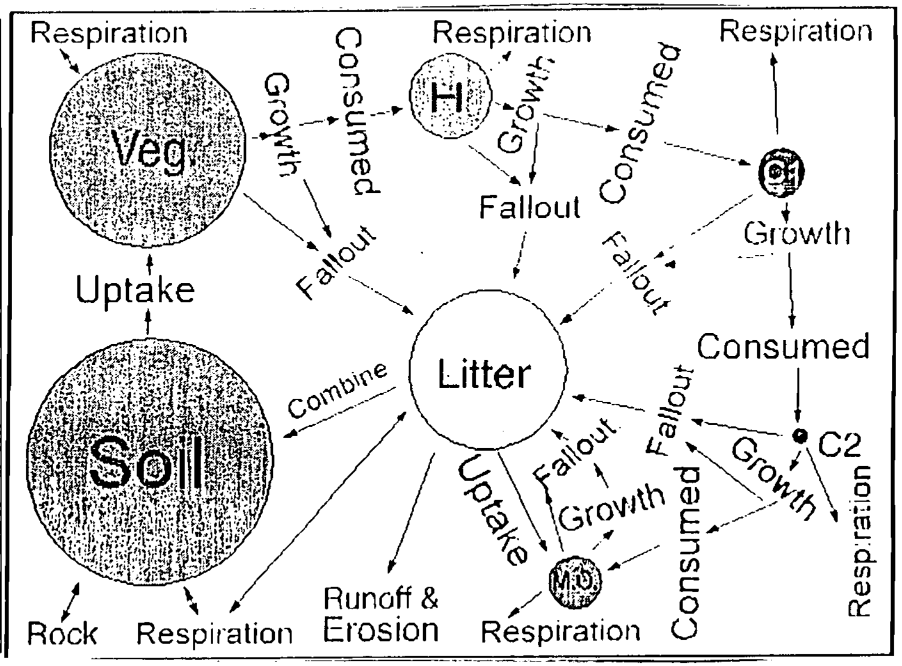
Top carnivores evolved to consume nutrients in other carnivores and herbivores.



Carrion eaters joined the nutrient cycle to consume dead carnivores and herbivores.

Micro-organisms clean up after all organisms, returning nutrients to the soil.

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Supporting Materials for the Activities

The following pages contain all those *Supporting Materials* referred to in the Activities. They are numbered according to the activities in which they are used. For example, *Supporting Material 1.5* would accompany Activity 1.5. Use these materials as overheads or handouts for students, especially when other resources are not available at your institution.

Note that the first item, *Supporting Material 1*, is somewhat of an exception to the notational scheme. It is a general handout that accompanies the module as a whole rather than just a particular activity. We recommend introducing it to the class early on since it is meant to help students acquire the essential skill of note taking from readings.

Taking notes that make sense -- even a year from now ...

As you work through the reading assignments for this and the following exercises, do not just read the articles, or just underline important passages. For understanding and remembering the arguments it is even more important to take notes on what you read. Taking concise yet comprehensive notes is a big step in preparing for classes and exams and to recall something you read or heard about.

If you are experienced in taking good notes, proceed to do so as you read your assigned materials. If you feel you could use some guidance in how to improve on this skill, follow the steps outlined below.

Articles that are written well have at least:

- ❑ a descriptive and/or provocative **title**,
- ❑ a compelling or at least an internally consistent **argument**,
- ❑ an apparent, intuitively logical, and hierarchical **structure** (look for subtitles),
- ❑ an obvious **paragraph separation and sequence**, and
- ❑ a clear, understandable **language** (including correct grammar and spelling, clear sentences, explanation for new or unusual terms, avoidance of unnecessary jargon and verbiage, etc.)

1 Gather the most obvious clues!

Browse through the article and note on a piece of paper its structure by writing down the title and all the subtitles of individual sections in the sequence in which they appear in the text. Indent all the subtitles that belong to the same logical section (to the same level in the hierarchy of importance) by the same amount so you know they are of similar importance and logically belong together. If there are no subtitles, you need to look at the text a bit more closely: is there a sequence of themes that the author(s) go through in the course of the text? If you can discern them, list them in the sequence in which they appear. (You may also group them later into logical classes if you can discern any.)

<u>Example</u>:

The Nature and Consequences of Indirect Linkages Between Climate Change and Biological Diversity
- Introduction
- Overview of Indirect Geospheric Linkages
  - Coastal Upwelling
  - Wildfire
  - Timing of Snowmelt
  - Soil
- Species Interactions
- Linkages with Other Anthropogenic Stresses
- Research Needs
  - Improving the Resolution of Climate Forecasts
  - Acquiring Useful Baseline Data
  - Conducting Field Manipulations
  - Using Correlations and Mathematical Models Effectively

Implications for Conservation Policy
Parks are not a Panacea
Other Solutions
Human Institutions: Part of the Problem, Part of the Solution
Summary

2 Put your mind's antennae out!

You can signal your brain to activate all the pertinent knowledge you already have about a subject by looking for titles and subtitles, as well as the logical structure of the text. These are the first hints as to the author's main argument in the text. The more conscious you become of these clues, the easier it will be for you to actually take in what someone writes.

So looking back at the above example, **what do you expect the text to be about?** (Note that in this exercise we are just being explicit about what your brain does automatically, whenever you get new information!).

3 Read the text (again)!

If you have not read the article yet, do so now. Stop once in a while and recall what you thought the text would be about. Are your expectations met? (If they are not, you will probably be quite frustrated and most likely bored!)

4 Note the main argument!

Given your expectation of the text and reading through it, what would you say is its main argument? In other words, if you were to explain the gist of the article to a friend who hadn't read it, what would you say?

5 Concisely list the supporting arguments under each heading (or subtitle)!

Every argument needs supporting arguments, data, and other evidence to be convincing. As you go through the text once more -- paragraph by paragraph -- list in keyword style or short sentences what the supporting evidence and arguments the author(s) presented. If you can't decide what is important and what is not (and thus should be omitted from this listing), ask yourself whether you found it important to know this particular item to understand the logic behind the argument. If not, leave it out! Everything that is not essential to the argument you are most likely to forget anyway.

6 Check whether it makes sense!

Once you're through with Steps 1-5, look over your notes once again and see whether they make sense. (The best test is really three days after taking the notes, i.e. when you're already somewhat removed from having read the article. If they still makes good sense, you took good notes!) If you feel like somewhere you lost the thread of the argument, fill in the blanks. Also compare the length of your notes with the length of the article: if your notes are as long as the original article, you simply paraphrased the text. Notes by definition are short and never as prosaic as an essay!

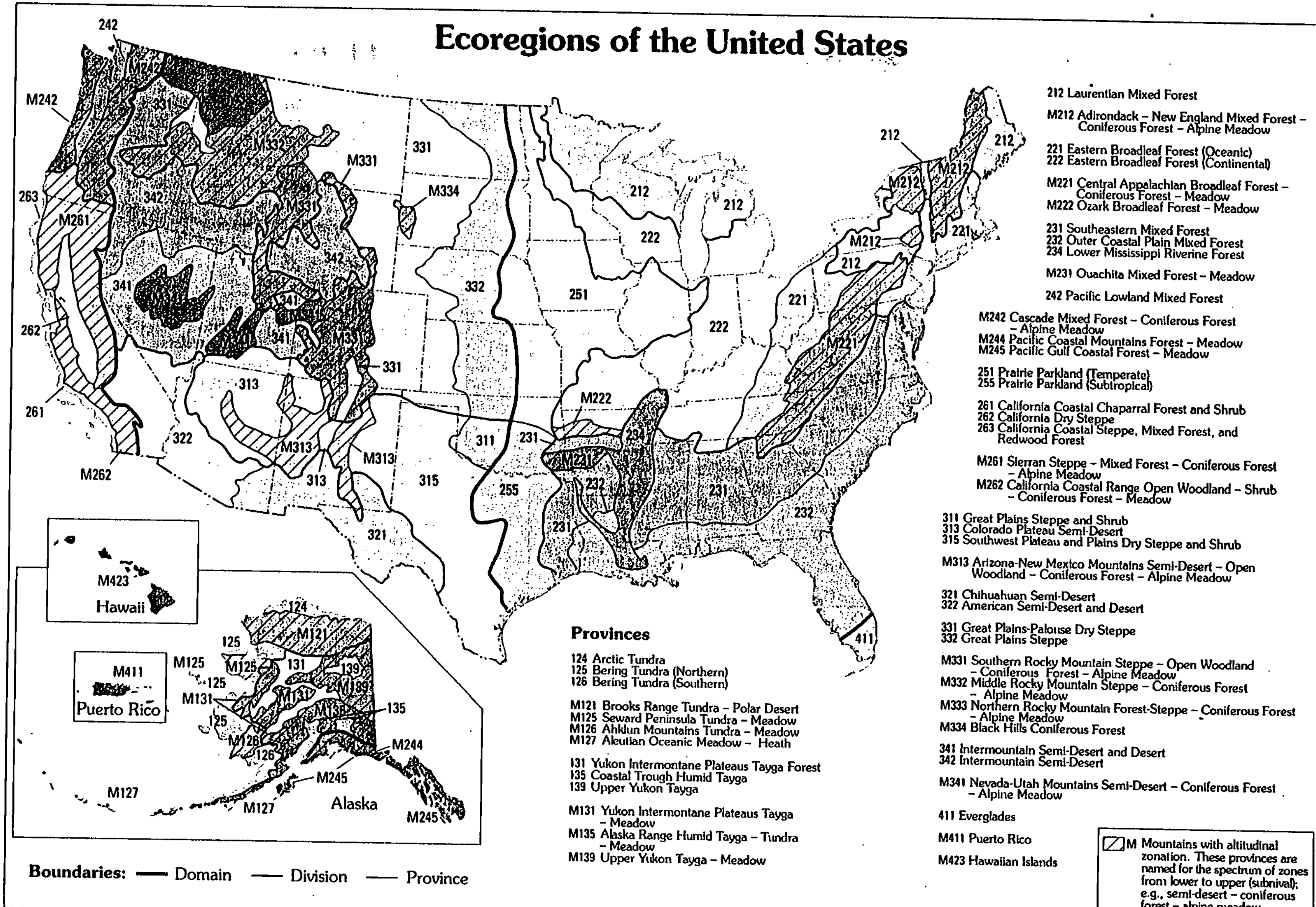
Map of Ecoregions of the United States of America

A black and white reproduction of a map of ecoregions is supplied on the next page. The colorful original is available with an accompanying report from the U.S. Department of Agriculture.

Source:

McNab, W. Henry and Peter E. Avers, comps. 1994. *Ecological subregions of the United States: Section descriptions*. Administrative publication WO-WSA-5. Washington, DC: U.S. Department of Agriculture, Forest Service.

Ecoregions of the United States



Source: R.G. Bailey [Ecoregions of the United States, USDA Forest Service (scale 1:7,500,000, revised 1994)]

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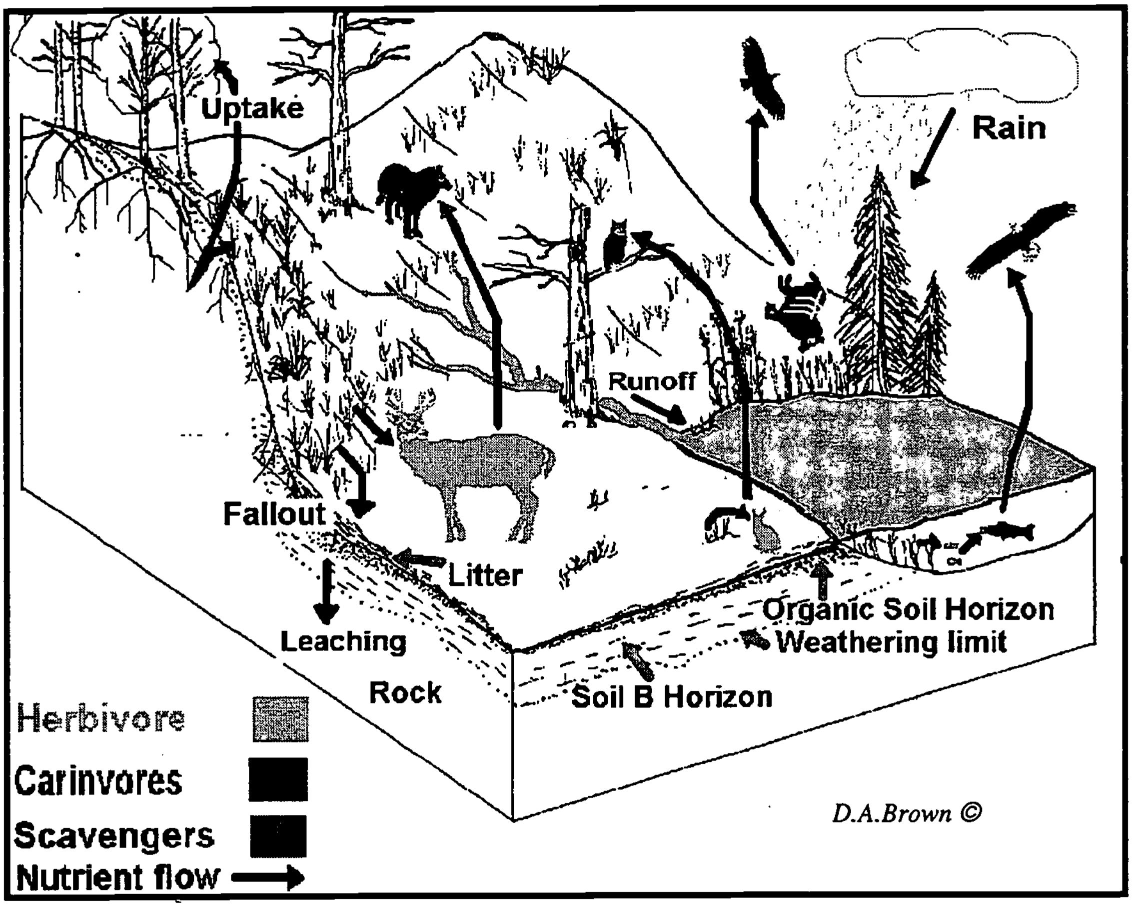
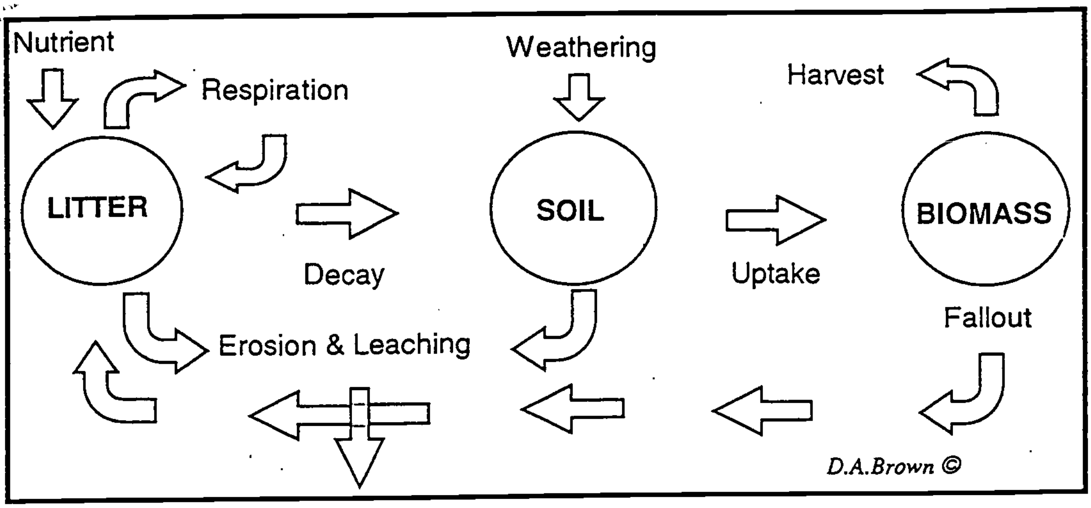


The nutrient flows in an ecosystem food web. An ecosystem is composed of plants and animals living together in an environment that has abiotic resources of soil (partly biotic), water, and air. In the schematic diagram above, only a few of these components and their interactions are illustrated. Small biotic elements are not included here. These include insects and microorganisms (decomposers) that play a major role in the breakdown of litter (organic material on the soil surface that is not fully decomposed and reintegrated into the organic component of the soil). Ecosystem productivity (the amount of biomass/organic material produced) depends on the ability of the vegetation (primary producers) to use solar energy to capture atmospheric carbon (in a process called photosynthesis) in exchange for oxygen and water vapor (respiration), and its ability to withdraw water and nutrients (nitrogen, phosphate, potassium, calcium, and other elements) from the soil (uptake). The next level of biotic elements in the food web (herbivores) capture part of the nutrients produced by the vegetation. Some nutrients are not consumed and most of what is consumed is lost to respiration and fallout (hair, feathers, skin, feces, urine). Carnivores (meat eaters) consume the herbivores, again converting only a portion of the available herbivore biomass to carnivore biomass. Complete consumption of a lower level would result in extinction of that level and consequently of all levels above. Dead animals and plants become litter, which is the food source for scavengers. The remaining plant and animal litter supports insects, bacteria, and other micro-organisms that convert the nutrients left in the litter back into a form that primary producers can take up, thus closing the nutrient cycle.

Simplified Ecosystem Nutrient Cycle Model. In the example below only the primary production trophic level is shown. Harvest by humans or other animals occurs if the material is removed from the site; otherwise the consumed portion of vegetation is returned to the system as fallout. The circles represent ecosystem nutrient reservoirs (storage compartments). Two independent inputs are involved: (1) the nutrients provided through soil development from the soil parent material (weathered rock) and (2) nutrients contributed from the atmosphere to the surface with precipitation or as dry atmospheric deposition (dustfall). Nitrogen, for example, can volatilize and then flow to and from the atmosphere. To simplify the model, we can consider respiration as a positive net input. The ecosystem would collapse if the balance was sustained as negative. All other transfers in the model are set as annual rates (percent) multiplied by the storage in the contributing nutrient reservoir. Harvest, erosion, and leaching represent losses to the local ecosystem. In many managed ecosystems, there is additional human input of nutrients through fertilization.



The model above can be expressed as a series of equations for each annual time step and for each nutrient storage compartment in the simulation model we use in this activity.

$L_1 = (L_0 + (B_0 * f) + n + r) - ((L_0 * d) + L_0 * e)$.
$S_1 = (S_0 + (L_0 * d) + w) - ((S_0 * u) + S_0 * l)$.
$B_1 = (B_0)(S_0 * u) - ((B_0 * f) + B_0 * h)$.

Where: d = decay, e = erosion, f = fallout, h = harvest, l = leaching, n = nutrients applied, r = respiration, u = uptake, w = weathering, and for time period 1, L_1 = litter, S_1= soil, B_1= biomass. Loss rates from a compartment cannot total more than 100%. If all nutrient storage compartments started (at time 0) with 33 units and the transfer rates were as follows; $d = 0.9$, $e = 0.05$, $f = 0.05$, $h = 0.0$, $l = 0.2$, $n = 0$, $r = 9$, $u = 0.7$, and $w = 0.01$, then at time 1 we would get:

$L_1 = (33 + (33 * 0.05) + 0 + 9) - ((33 * 0.9) + 33 * 0.05) == 43.65 - 31.35 = \mathbf{12.3}$
$S_1 = (33 + ((33 * 0.9) + 0.01) - ((33 * 0.7) + 33 * 0.02) = 35.71 - 29.7 = \mathbf{6.01}$
$B_1 = (33 + (33 * 0.7) - ((33 * 0.1) + 33 * 0.0) = 56.1 - 3.3 = \mathbf{52.8}$

In this example, the high transfer rates result in a rapid adjustment, i.e., it would take only a brief period before the nutrient storage in the different compartments would stabilize.

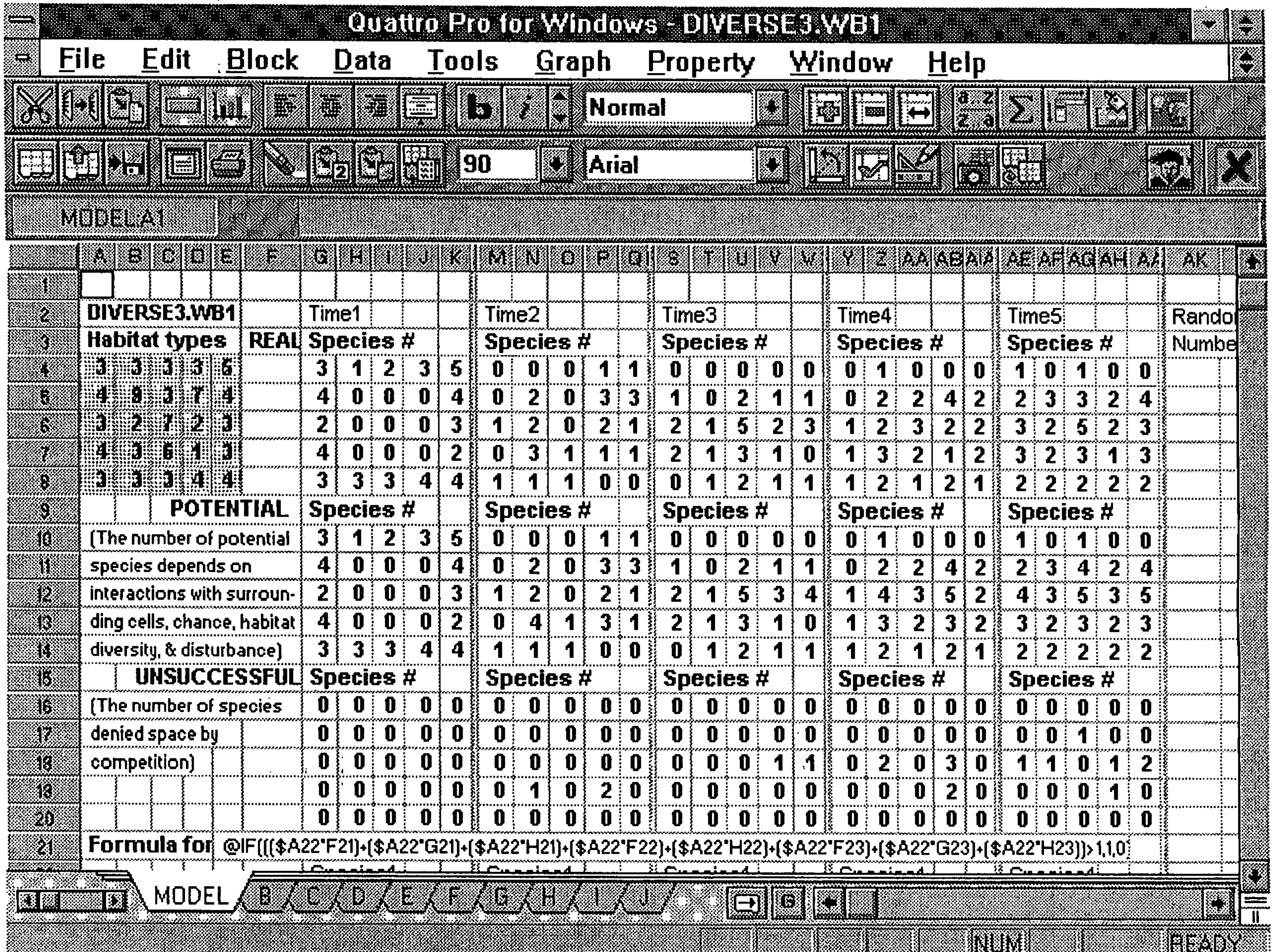
Simulation. In the highly generalized mathematical model we use here, the high transfer rates between compartments are partly controlled by temperature and water availability. Human-induced climate changes alter the rates of these nutrient transfers by altering the water balance and by changing the temperature regime in ways that favor some plants and decomposing organisms over others. If temperatures exceed the optimum range for all plants and decay organisms present, production will decrease. Modeling these effects would require adjusting the uptake, fallout, and decay rates in the model to reflect possible ecosystem responses to climate change. By modeling the effects of a single element change, such as fallout rates, we can test how such changes cascade through the system. Only in the world of simulation modeling can we treat one variable at a time. Otherwise, as in the conversion of tropical rainforest (selva) to rangeland, flow rates and storage levels change concurrently. Such a land cover change radically alters the biomass fallout rate while also changing the range of plant species which translates to a change in the rate of nutrient uptake from the soil.

Some Background Information on the Biomes Selected for this Activity

Selva biomes exist in areas where temperatures and rainfall are sufficiently high that evergreen plants do not experience low temperatures or water stress. The vegetation is dominated by broadleaf evergreen forest, found extensively within 20 ° of the equator. The selva has by far the highest net primary productivity of any terrestrial ecosystem (~ 2000 grams/meter^2/year). The mix of species is extremely high. That complexity was once thought to indicate very long evolution of the plant assemblage; however, analysis of fossil pollen indicates that the assemblages we see today have existed for only a few hundred to a few thousand years. Most of the plants are shallow rooted because of the reliability of precipitation and the fact that nutrients are captured before they go very deep. In fact, some trees have root systems that envelop their own trunk, presumably to capture the nutrients in water flowing down the stem. This adaptive strategy denies these nutrients to other plants. The soil resources of tropical rainforests are highly varied, but high acidity, low fertility, and low accumulation of surface litter are common traits of soils under selva.

The **tundra** biome represents the cold extreme among terrestrial biomes. These are cold deserts, but low plant demands for water (because temperatures hold down transpiration rates during a very short growing season) and the frozen substrate keep soils moist. The freezing temperatures for much of the year and the often saturated surface keep decomposition rates low, but biomass production is similarly low. Except for extremely low latitude deserts, the tundra has the lowest net primary productivity of any terrestrial ecosystem, (~ 150 grams/meter^2/year). The species mix is very low and is dominated by sedges, grasses, dwarf willows, mosses, and lichens.

The **steppe** or grassland biome's net primary productivity has a very wide range (~ 700 +/- 500 grams/meter^2/year). Before vast human alteration for agriculture, the steppe was the most abundant biome on earth. Most of the world's great grain producing regions were carved from grasslands. The soils are well drained; they have high nutrient holding capacity because of the quality of the clay minerals present and the high amount of organic matter in the surface horizon. Prior to cultivation, the nutrient status of grassland soils was very high.



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7	4	3	6	1	3		4	0	0	0	2	0	3	1	1	1	2	1	3	1	0	1	3	2	1	2	3	2	3	1	3	
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12	interactions with surroun-						2	0	0	0	3	1	2	0	2	1	2	1	5	3	4	1	4	3	5	2	4	3	5	3	5	
13	ding cells, chance, habitat						4	0	0	0	2	0	4	1	3	1	2	1	3	1	0	1	3	2	3	2	3	2	3	2	3	
14	diversity, & disturbance)						3	3	3	4	4	1	1	1	0	0	0	1	2	1	1	1	2	1	2	1	2	2	2	2	2	
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17	denied space by						0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	
18	competition)						0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2	0	3	0	1	1	0	1	2	
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20							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Row 21: Formula for @IF((($A22*F21)+($A22*G21)+($A22*H21)+($A22*F22)+($A22*H22)+($A22*F23)+($A22*G23)+($A22*H23))>1,1,0

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Annotated Bibliography of Additional and Supplementary Readings

The following readings are suggested as introductory papers to biogeography, to the connection of biogeography and the human dimensions of global environmental change, or as case studies to accompany Activity 3 and others. Depending on the larger scope and purpose of your course in which this module is being used, these articles may also lead to related topics or deepen students' and instructors' understanding of issues discussed here (e.g., land use and land cover change, the significance of biodiversity loss to society).

Bergelson, Joy. 1996. Competition between two weeds: Groundsel and Bluegrass compete based on germination, litter and open parcels. *American Scientist* 84, 6: 579-584.

A short, easily readable article that addresses several of the themes of this module (dispersal, productivity, population, species diversity under varying environmental conditions). It's a good follow-up to the more abstract discussion in the *Background Information* using a common example.

Goudie, Andrew. 1986 (or any later edition). *The human impact on the natural environment.* Oxford: Basil Blackwell. (See especially the chapters on human impact on vegetation and on soils.)

A classic text in introductory geography that introduces the subject of this module. The chapter on human impacts on vegetation gives a broader overview than is provided in this module, discussing various basic ways in which vegetation can be impacted and how these affect (and even create new) ecosystems and biomes (savanna, secondary rain forest, prairie landscapes, etc.). A similar broad overview is given in the chapter on soils.

Holling, C.S. 1995. Sustainability: The cross-scale dimension. In: *Defining and measuring sustainability: The biophysical foundations*. Mohan Munasinghe and Walter Shearer, eds., 65-75. Tokyo, New York: United Nations University and The World Bank.

This is a challenging if short piece by an ecology authority who knows how to put geography to work, and who is not afraid to seek analogies between ecological and social systems! The chapter gets at the module concepts of diversity, disturbance, pattern, and connectedness among ecosystem components across various scales. Holling applies these to a discussion of defining "sustainability" and as such goes beyond the module per se. A stimulating and long-lasting piece for the advanced reader. Alternatively, an instructor could walk students through the text -- it's cutting-edge ecology/biogeography and worth the effort.

Kareiva, Peter M., Joel G. Kingsolver, and Raymond B. Huey, eds. 1993. *Biotic interactions and global change*. Sunderland, MA: Sinauer Associates Inc.

A broad-ranging anthology of the current state of the art in biotic changes in response to global climate and other changes. Contributions vary from an introductory section on how and why landscapes change to how the physiology and populations of organisms change in response to environmental change, to evolutionary and community-scale responses to environmental change, to a number of contributions on landscape change and habitat fragmentation.

LaRoe, E.T. *et al.*, eds. 1995. *Our living resources: A report to the nation on the distribution, abundance and health of U.S. plants, animals, and ecosystems.* Washington, DC: U.S. Department of the Interior, National Biological Service. (Gov. Printing Office, Stock # 024-010-00708-7).

An excellent resource! Pick any U.S. plant, animal, ecosystem, or major human-induced impact and find crucial references to the subject in this 530 page book. Short summaries for each describe the distribution, abundance, and state of health or ill-health of the particular plant, animal, biotic community or issue you are interested in. Not an exhausting account but a great starting point for student projects, or for the instructor to read up on something quickly. (See also Root and Weckstein; Oglesby and Smith; and Morse, Kutner, and Kartesz elsewhere in this annotated bibliography.)

McNab, W. Henry and Peter E. Avers, comps. 1994. *Ecological subregions of the United States: Section descriptions.* Administrative publication WO-WSA-5. Washington, DC: U.S. Department of Agriculture, Forest Service.

The report is an accompaniment to a wonderful, colored map of U.S. ecoregions. (A small black and white copy is included in the *Supporting Materials* section of this module.) The descriptions for each ecological section include summaries of geomorphology, geology, soils, vegetation, fauna, climate, disturbance regimes, current land sue, and cultural ecological aspects pertinent to the section. A good background resource, and possible basis for some of the activities.

McNeely, Jeffrey A. *et al.* 1990. *Conserving the world's biological diversity.* Washington, DC: World Resources Institute.

A comprehensive book explained the meaning and importance of biodiversity and the threats to it while also showing with many practical examples from around the world how it can be preserved. (Also available from Earthscan Books.)

Morse, Larry E., Lynn S. Kutner, and John T. Kartesz. 1995. Potential impacts of climate change on North American flora. In: *Our living resources: A report to the nation on the distribution, abundance and health of U.S. plants, animals, and ecosystems.* LaRoe, E.T. *et al.*, eds., 392-395. Washington, DC: U.S. Department of the Interior, National Biological Service.

A short research article that examines the vulnerability of different plant species to climate change. What is it that does or doesn't allow a species to adapt to altered climatic conditions? The article discusses species rarity, vulnerability, dispersal, persistence, ability to migrate, disturbance, and landscape fragmentation in order to understand potential impacts on the abundance of species. A very good reading to accompany this module!

Oglesby, Ray T. and Charles R. Smith. 1995. Climate change in the Northeast. In: *Our living resources: A report to the nation on the distribution, abundance and health of U.S. plants, animals, and ecosystems*. LaRoe, E.T. *et al.*, eds., 390-391. Washington, DC: U.S. Department of the Interior, National Biological Service.

A short research article that reports on investigations of date changes of first bloom of flowering plants and of first arrival of migratory birds over a 70-90 year period which indicate that there is a steady trend to earlier bloom and earlier arrival. The authors explain this by a warmer climate and discuss alternative explanations.

Peters, Robert L. and Thomas E. Lovejoy, eds. 1992. *Global warming and biological diversity*. New Haven, CT: Yale University Press.

Compared to the Kareiva *et al.* anthology, this edited volume is more narrow in focus: of the global changes, it is mainly concerned with global warming, and of the biotic aspects, it concentrates on biological diversity. Yet, the geographic and methodological coverage is exemplary. The chapters in the book discuss biodiversity in various types of habitat and climatic zones, and they present several methods to study biological changes ranging from the analysis of geological records to computer modeling of biological responses to global warming. Of particular relevance to this module are chapters on changes in range, competition, and composition of ecosystems, on population dynamics, and on responses of soils and biotic processes in soils to climate change.

Reid, Walter V. and Kenton R. Miller. 1989. *Keeping options alive: The scientific basis for conserving biodiversity*. Washington, DC: World Resources Institute.

A short book that discusses the value of biodiversity, the degree of endangerment, and the choices over what should be conserved, and how, using the best available scientific information at the time. Still a valuable resource.

Root, Terry L. and Jason D. Weckstein. 1995. Changes in winter ranges of selected birds, 1901-1989. In: *Our living resources: A report to the nation on the distribution, abundance and health of U.S. plants, animals, and ecosystems*. LaRoe, E.T. *et al.*, eds., 386-389. Washington, DC: U.S. Department of the Interior, National Biological Service.

One of the short overview research articles included in this compendium that investigates range changes of birds over 90 years in relation to climate change in the United States. An interesting example of research methodology as much as of the results that indicate significant changes.

Rosenzweig, Cynthia and Daniel Hillel. 1993. Agriculture in a greenhouse world. *National Geographic Research & Exploration* 9, 2: 208-221.

A scientific, yet very readable article about the likely environmental changes as a result of global warming that will affect agriculture. The authors discuss physiological effects of CO_2 enrichment, thermal changes, hydrological changes, changes in climatic variability, soil fertility and erosion, pests and diseases, and interactions between agricultural and natural ecosystems that will differentially alter agricultural productivity across the globe.

Stevens, William. 1992. Global warming threatens to undo decades of conservation efforts. *The New York Times*, February 25, 1992.

An article that reports on the impacts of global climate change on ecological systems in general, and on Peter and Lovejoy's book mentioned elsewhere in this bibliography in particular. In short, a quick and good, readable account of some potential impacts of climate change on biological systems with a distinct geographic slant since it juxtaposes human-set boundaries around nature reserves with the ever-changing range shifts of species.

Turner, B.L. II, R.H. Moss, and D.L. Skole, eds. 1993. *Relating land use and global land-cover change: A proposal for an IGBP-HDP Core Project.* IGBP Report No. 24/HDP Report No. 5. Stockholm: IGBP.

A scientific text that focuses primarily on land use and land-cover change yet is relevant to this module in that it looks at relatively unaltered natural ecosystems and human-altered environments, and relates changes occurring on a global scale to the human dimensions of global change (driving forces, impacts, responses).

Valiela, Ivan *et al.* 1996. Hurricane Bob on Cape Cod. *American Scientist* 84, 2: 154-165.

An excellent illustration of the impacts of extreme, however sort-lived disturbances on a New England habitat. Very accessible; well illustrated.

Vitousek, Peter M. *et al.* 1996. Biological invasions as global environmental change. *American Scientist* 84, 5: 468-478.

This article by one of the authorities (and coauthors) on global biological changes does not only touch upon one of the principal themes of this module -- invasion, it also views the interaction between the biosphere and global change from a slightly different angle: rather than looking at the *impacts* of global change on the biosphere, Vitousek *et al.* show that biological changes like species invasions constitute a type of global change.

Wilson, Edward O. 1990. Threats to biodiversity. In: *Managing planet Earth: Readings from Scientific American*, 49-60. New York; W.H. Freeman & Co.

Wilson focuses on habitat fragmentation, mainly through deforestation in the tropics, and its impacts on species diversity. A good read on destructive human interference in natural processes.

World Resources Institute. 1992. *Global biodiversity strategy: Guidelines for actions to save, study, and use earth's biotic wealth sustainably and equitably.* Washington, DC: World Resources Institute.

A great resource for the practically oriented. A book of policy-oriented steps for public and private sector decision-makers to preserve biotic resources <u>and</u> how to pay attention to the social and economic contexts in which such decisions have to be made. Also includes background information, a glossary, list of acronyms common in this field, and an accounting of biodiversity loss as of the date of publication.

Appendix: Readings

The AAG was able to obtain reprint permission from the original publishers for only some of the readings suggested in the activities of this module. To avoid copyright problems, we suggest you make these two readings available to your students by putting them on reserve. The following readings are enclosed:

1) Brown, Dwight A. 1995. *Biological resource geographies*. Minnesota, MN: University of Minnesota. Reprinted with the permission of the author.

2) Morse, Larry E., Lynn S. Kutner, and John T. Kartesz. 1995. Potential impacts of climate change on North American flora. In: *Our living resources: A report to the nation on the distribution, abundance and health of U.S. plants, animals, and ecosystems*. LaRoe, E.T. *et al.*, eds., 392-395. Washington, DC: U.S. Department of the Interior, National Biological Service.

APPENDIX A:
READINGS FOR *LIVING IN THE BIOSPHERE*

BIOLOGICAL RESOURCE GEOGRAPHIES

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BIOLOGICAL RESOURCE GEOGRAPHIES

Dwight A. Brown ©
July 9, 1995

INTRODUCTION

Biological resources of substantial geographic concern fall into two categories, natural biological systems and managed biological systems. These two subsets of biological resources will be examined in order. Then, the principles will be applied by analyzing the issues of deforestation and desertification, and crop genetic diversity. The managed biological systems are of most direct concern in support of human life, and as such are the focus of immediate concern when we consider climate change and particularly the potential for human induced global warming.

Before we examine the various issues that surround biological resources we need to set a common vocabulary and an understanding of basic processes and fundamental principles.

Terms

- **Ecosystem**: System of interacting organisms in their environment.
- **Biome**: Community of distinctive flora, fauna, soils and climate conditions.
- **Ecotone**: Transition area between two biomes.
- **Niche**: A place or position in an ecosystem.
- **Symbiosis**: Living together of 2 dissimilar and mutually dependent organisms.
- **Species**: Highest taxonomic level of organisms that can reproduce.
- **Trophic level**: One of the levels in a food web.

Processes

Evolution, adaptation, and extinction. Evolution is the continuing inter-generation organism change processes that are the product of DNA capabilities. Adaptation is change that can involve evolution or the individual organisms response to resource or hazard changes.

Mass transfers. Material is cycled, stored, and recycled in a system of production and consumption and decomposition.

Dispersal or migration. Organisms or populations move or change their distributions.

Principles

- **Ultimately, all biomass is dependent on solar energy**. All growth requires energy inputs.
- **Nothing is independent of other things**. All organisms affect their environment and are affected by it.

- **Mass and energy are conserved.** Things don't go away they just get moved or changed in state. This is fundamental to the material cycling in the environment.
- **There is a tax when energy is moved to another trophic state.** The amount of biomass in one trophic level that can be supported by the consumption of organisms at a lower trophic level must be less than the biomass of the consumed organisms. The reason is that all biological systems gain biomass only after they have met the energy needs for maintenance of their weight and life functions. This is termed feed efficiency in domestic livestock.
- **There is a tax on the virulence of pests over time.** Invading organisms are more virulent early in their invasion history. Invading organisms play a role in the adaptive change of host organisms. No invader resides long without gaining pests or predators.
- **Nothing is moved without some cost to something.** This is another expression of Newton's first law of motion. Energy is required from somewhere to overcome the rest inertia of a mass.
- **Human-induced changes may not may not improve natural conditions.** Here we move into the philosophical realm of "improve" and "for whom", and in what context. It is difficult to put a neutral spin on some environmental changes. In early environmentalist literature this principle was stated as "nature knows best", but nature too has been extremely harsh. Throughout geologic history major disasters have resulted in the extinction of vast numbers of plants and animals. In some natural disasters, like the eruption of Krakatau, the environmental damage may be viewed positively as an opportunity for new organisms. The roles of humans and natural processes cannot always be separated in the analysis of changes.

Our understanding of these terms, processes, and principles is based or reinforced by observation. They are mental constructs, and as such should be subjected to continual scrutiny. As we accumulate more observations we may challenge the validity of our ideas and may even reject them, should they prove to be misleading or unsupportable.

GEOGRAPHY OF NATURAL BIOLOGICAL SYSTEMS

The explanation of plant and animal patterns and their dynamics is a central theme of biogeography. Plant and animal patterns are the product of 3 process suites that continuously work to change both the nature of the organisms and their distributions. The first explains what genetic resources are available, the second explains their pattern, and the third set of processes explains the productivity of genetic resources in a place.

I. What genetic resources are available? Throughout geologic time, genetic resources have continually changed through the processes of **evolution**, **adaptation**, and **extinction**. The dynamics of environments require the recurring creation of new genetic material better capable of functioning under new conditions.

New species and varieties need opportunities to survive, and the chances are aided by extinction. Although extinctions are common throughout geologic history, there have been periods of major global extinctions. Recently human actions have been responsible for complete and near extinction of numerous species. The attached graph of North American Genera (Fig. 1) shows the history of arrivals and disappearances over the past few million years. The arrival of humans in North America was followed by the disappearance of 34 genera of mammals from the continent. We cannot blame humans completely because other causes of extinction continued to operate.

II. How are genetic resources patterned? **Disturbance**, **dispersal**, and **establishment** processes govern the invasions of organisms, and are responsible for the transfer of genetic material from one place to another. The success of these processes controls the biodiversity of places. Biodiversity is threatened both by reduction of the inventory of genetic materials and by the interruption of disturbance processes, which are necessary for the establishment of replacement materials move to establish in a territory.

III. How productive is a place? This third set of processes governs how nutrients are allocated to various environmental compartments and trophic levels. It includes the **energy flows** that drive and regulate the carbon, oxygen, nitrogen, and phosphorous cycles. It involves how organisms transfer materials to alter their own environment and sustain their own life and population systems. The first trophic level, **primary production**, uses solar energy to fix atmospheric carbon into organic carbon.

Plants are the primary producers of the food web. They provide the foundation for all animal life. They fix atmospheric CO^2 into plant materials that contain essential nutrients derived from the soil. Plants selectively let different elements of the soil solution (soil water that contains dissolved minerals) into the root membrane. Each species has a range of materials that come into the plant tissue and there are differences in that selectivity. Some of these differences may be viewed as adaptive strategies to defend against predators (Table 1).

The kinds of plants vary geographically at the global, continental, and landscape scales. At the global scale, the productivity of plants differs substantially (See Fig. 2). The kinds of plants that inhabit a place change through time. These changes are facilitated by processes that disturb existing plants and make the space available for new invaders. All plant and animal populations are the result of invasion events at various times. The patterns of populations on the globe is not simply determined by climate and other physical characteristics of a place; they are shaped by the opportunities for species to disperse and invade a place. Some of the opportunities that make space available for new invaders are shown in Table 2. These external forces operate selectively at the expense of some types of plants, while favoring others from the surrounding genetic resource pool. This selective advantage or disadvantage of organisms is the basis for arguing that diversity is important to long-term productivity. A very diverse assemblage of plants increases the likelihood that suitable colonizers of that space are already close and production will not sag for long after space becomes available.

Figure 3 shows the patterns of populations that reflect this process. Other patterns are disintegrating and reflect the disturbance patterns and the greater success of other species. Most plant populations that have been studied have not established themselves over their full potential climatic range. This is because dispersal processes are driven by the conditional probabilities of (1) the chance that a seed will reach a suitable area and (2) the chance that there is space available for it to germinate, emerge, mature and reproduce. Figure 4 shows the dominance graphs of three major native grasses. (Each number represents a county. High numbers indicate greater importance of the grass species in that county. The location of the number on the graph indicates the county's climate.) If these species had extended to their full climatic ranges, there would not be large differences in the importance of a particular grass between counties of similar climate (large and small numbers would not be interspersed in the graph space).

The place of the most genetic diversity of a genera is assumed to be the sources from which dispersal of a species originated. From the maps of species numbers in Figure 5, we can infer western, southwestern, and southeastern source areas for those grasses. The relative dominance patterns and morphologies of nine major grass species are shown in Figure 6-9. Note that little bluestem (*Schizachyrium scoparium*), Indiangrass (*Sorghastrum nutans*), and big bluestem (*Andropogon gerardii*) dominate the eastern side of the Midcontinent Plains grasslands, while needleandthread (*Stipa comata*), Western wheatgrass (*Agropyron smithii*), and green needlegrass (*Stipa viridula*) dominate western or northwestern areas of the plains. The dominance of black grama (*Bouteloua eriopoda*), blue grama (Bouteloua gracilis), and sideoats grama (*Bouteloua curtipendula*) focus on the southwestern Plains. These patterns of abundance correspond with the patterns of origin shown in Figure 5.

Grasses are not the only plants to display dispersal processes in their abundance patterns. Margaret B. Davis (1983) studied the history of tree movements since the last continental glacier melted (See Figure 10). Two distinctly different migration patterns are detected among eastern trees. Pines and hemlock moved toward the northwest from a Mid-Atlantic coast source, and the others moved toward the northeast from Tennessee, where they persisted during the last glacial maximum.

The climatic, and human contexts of these tree migrations is not known, but the differences among these distributional adjustments is increasingly viewed by paleobotanists as evidence for rejecting the deterministic paradigm that held vegetation patterns as directly determined by climatic. They are also used as evidence for natural dispersal rates for trees. These rates of migration indicate that most trees would not be able to keep in step with theorized climate changes over the next 50 years. Even in the absence of major human barriers to migration, the rate of adjustment of trees patterns would lag substantially behind the human-induced climate change. The response of other plant patterns to climate change is also of concern. The water use efficiencies and temperature responses of different plant types cause us to expect different responses. The root of some of the major response differences lies in the photosynthetic process.

Most plants have one of two photosynthetic systems in their leaf structure for fixing atmospheric carbon dioxide into plant carbon. These two leaf anatomies, known as C3 (cool season plants) and C4 (warm season plants) have optimum production temperatures. The optimum temperature for production by C3 plants is about 20^{o} C and 35^{o} C for C4 plants. These differences in the response of productive to temperature were observed in agricultural crops long before the leaf anatomy and biochemical processes were understood. As The production response curves in Figure 5 indicate, C3 plants have the potential to be most affected by global warming. This includes most woody plants and some grasses. Among the agricultural crops most vulnerable to heat stress are wheat, oats, barley, and rye. Beans and other legumes like alfalfa and clover are also C3 plants.

Farmers combat this photosynthetic limitation of small grain crops by planting the annual crop in the fall, allow it to go dormant over winter and complete growth before the temperatures get too hot. Wheat (winter wheat) is successfully planted in this manner, but not all grains survive winter well enough to use this forced adjustment of the plants phenology. As more winter hardy varieties of wheat have been developed, the region of winter wheat production in the United States has slowly drifted northward. Figure 11 shows the current distribution of winter wheat and spring wheat production in the United States. Global warming might necessitate further shift from spring wheat to winter wheat. The losers would be those crops, like soybeans and some small grains, that cannot survive winters.

One factor that adds uncertainty to estimating the response of C3 crops to global warming induced by greenhouse gasses is the fact that this photosynthetic system is presumed to have evolved at a time when the global atmosphere had 10 times the CO_2 content than the modern atmosphere. Experiments show that there is a positive production response of these plants to elevated CO_2 levels. C4 plants don't share this production response.

Other domestic grass crops are C4 plants (corn and various sorghums). These plants evolved in the tropics and benefit from high summer temperatures. These plants are also more efficient users of water, but global warming may in some areas result in more negative water balances and reduce yields. A strategy for combating climate change is for the area of production to shift with the climate, but there is a rub. The spaces of expected favorable climate will not correspond to the optimum soils, topography, or market location (Figure 11).

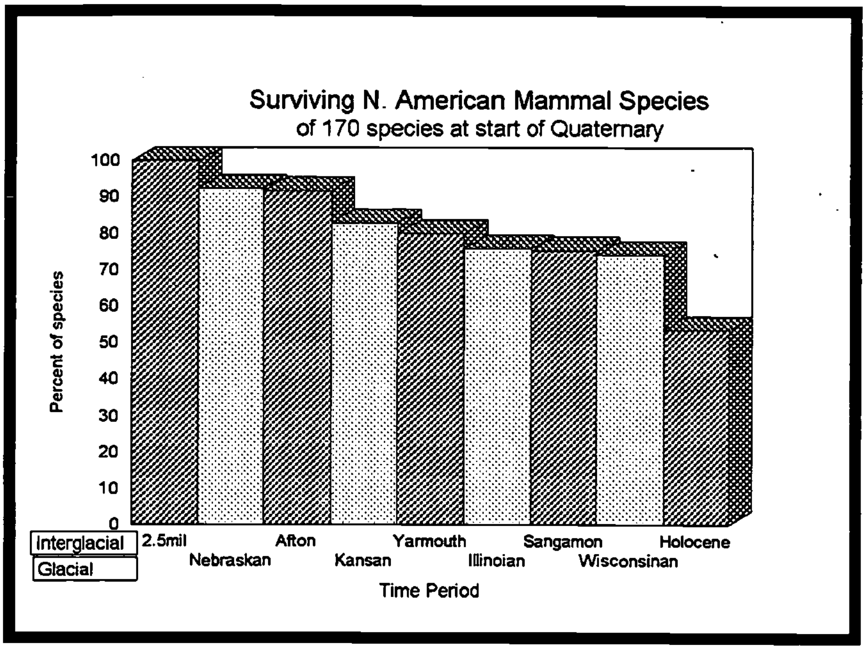

Figure 1. Extinction of North American mammal species that lived in North America at the beginning of the Quaternary Period. The greatest species loss occurred between the Wisconsinan glacial episode and the Holocene (the present interglacial). That period coincides with the entrance of humans into North America. Their role in these mass extinctions are the subject of much speculation by scholars.

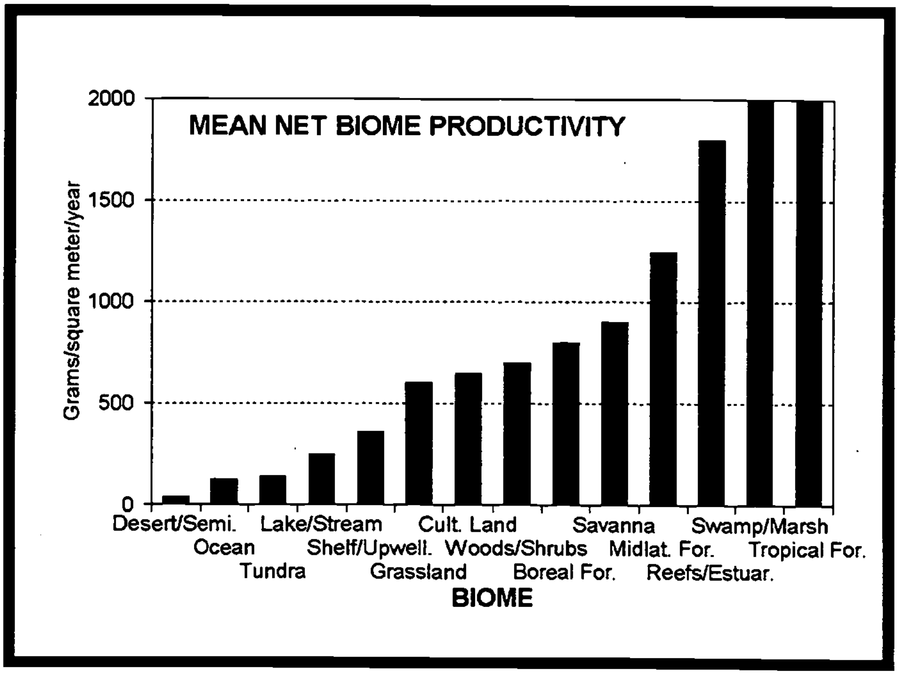

Figure 2. Productivity of selected major biomes.

Table 1. BIOTIC PERSISTENCE MECHANISMS

PLANT DEFENSES

Principle	Response	Plant Examples
Active Chemical Defenses		
Allelopathy	Rival plants weaken, die	Creosote bush, quackgrass
Passive Chemical Defenses Against Grazers		
Alkaloids	Poisonous to cattle	Low larkspur Tall larkspur (after blooming) Lambert crazyweed, Plains loco
	Weakness, trembling, Sheep liver damage	Tailcup lupine Gray horsebrush
Cyanogenetic glycocides		True mountain mahogany
Hydrocynaic acid		Chokecherry
Nitrates	Toxic	Ambrosia several (ragweeds)
Oxylates (of Ca, Na, K)	Death Death in sheep	Halogeton Black greasewood
Photosensitization	Catalyst of light sensitive skin,	St. Johnswort
	Facial swelling	Gray horsebrush
Prussic acid (after frost)	Death	Johnsongrass, sorghums
Saponin	Death/abortion	Broom snakeweed
(steroidal structure		Snowberry
glucoside causes foaming)	Spewing sickness	Orange sneezeweed
Selenium accumulation	Toxic	Curlycup gumweed, Blue penstemon, Jimson weed Desert princeplume
(with locine)	Loco	Woolly loco
Tannic acid	May kill digestive bacteria	Post, gambel, & blackjack oaks, sagebrush
Mechanical Defenses Against Grazers		
Spines, Thorns, Needles, & Stiff awns	Irritation & swelling, (especially to eyes, tongue, & lips)	Thistles, nettles, many trees and shrubs, coniferous trees, and many seeds, & many grasses,

Table 1. Continued.

ANIMALS CHEMICAL DEFENSES

Active (directed defense response)	Consequence to Predator
Skunks	Annoyance
Venomous Snakes	Death

Passive (result of ingestion)	Consequence to Predator
Poison-dart frogs of Columbia genus *Phyllobates*	Death
Pitohuis birds of New Guinea	Death

PLANT SURVIVAL STRATEGIES

Strategies	Plant Types	Hazards
Rapid seed germination	Selva and tundra plants	Biotic competition & heat, cold
Delayed germination	C4 grasses, oaks, pigweed	Drought
Vivipary	Mangroves	Biotic
Allelopathy (self)	Sunflowers, weeping lovegrass	(Not obvious)
(others plants)	Quackgrass, beech, creosote bush	Competing species
Serotinous seeds	Jack pine, Douglas fir	Fire
High seed numbers	Annual species	Biotic competition
Perennial growth habit	Many plant types	Reproductive uncertainty
Seed mobility	Needlegrasses, sandburs, cottonwood, cattails, dandelion	Fragmented habitat Pattern
Seed digestion resistance	Many with hard-coated seeds	Biotic
Adventitious rooting	Spruce, Aspen, Buffalograss	Drought, biotic, heat, cold
Nitrogen fixation by rhizobium bacteria on root nodules	Legumes: alder, beans, acacia alfalfa, lead plant, locust trees	Soil nitrogen deficiency
C4 photosynthesis	Warm season plants	Drought heat
CAM photosynthesis	Cactus	Drought heat
Restrict transpiration	Stomata closing, leaf drop leaf curl, waxy leaves	Drought, heat
Toxicity	Induce illness or death	Grazing, browsing
Mechanical	Irritation	Grazing, browsing

Table 2. CREATING SPACES FOR NEW PLANTS

Disturbance Mechanisms	Disadvantaged plants	Advantaged plants
Fire	Thin barked High growth center	Thick barked, Serotinous seeds
Nutrient depletion	All plants	Legumes
Soil toxicity	Variable	Variable
Allelopathy	Variable	Specific plants
Erosion	Shallow rooted	Rapid dispersing neighbors
Deposition	Low growth center	High growth center
Wallowing	Small plants	Tillering plants
Burrowing	Small plants	Tillering plants
Blow down	Shallow rooted trees	Shade tolerant understory
Stump plowing	Uprooted tree	Understory plants
Heat	C3 plants	C4 and CAM plants
Cold	C4 and CAM plants	C3 plants
Drought	C3 plants Shallow rooted	C4 and CAM plants Deep-rooted
Flood	Mesic & xeric plants	Hydrophytes,
Water table rise	Deep-rooted plants	Shallow-rooted plants, Hydrophytes, Phreatophytes
Water table drop	Shallow-rooted hydrophytes	Deep-rooted hydrophytes other shallow-rooted plants
Defoliation by grazers	Annuals	Perennials
Shading	Heliophytes	Heat sensitive plants

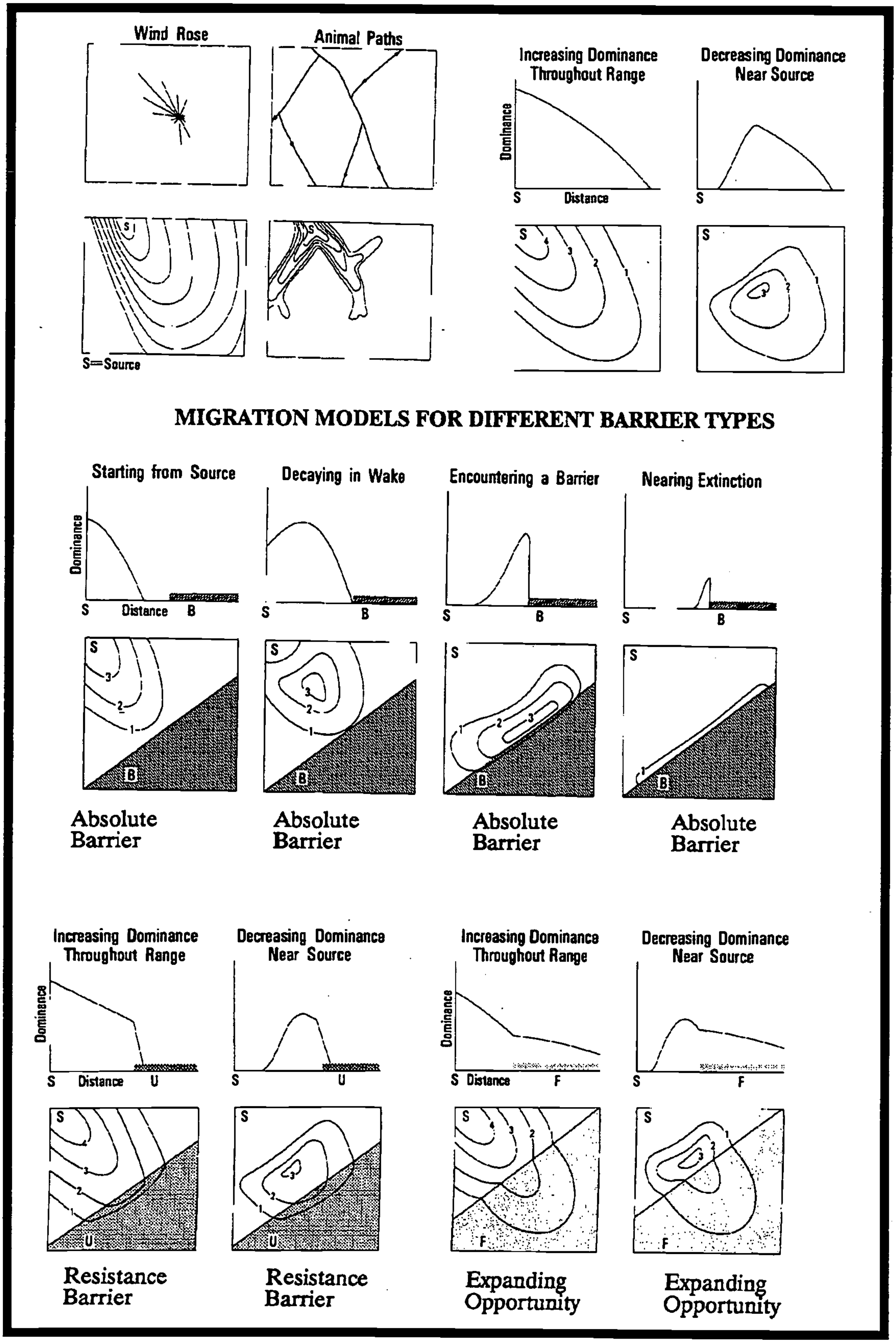

Figure 3. Theoretical models of plant dispersal (after Brown and Gersmehl 1985).

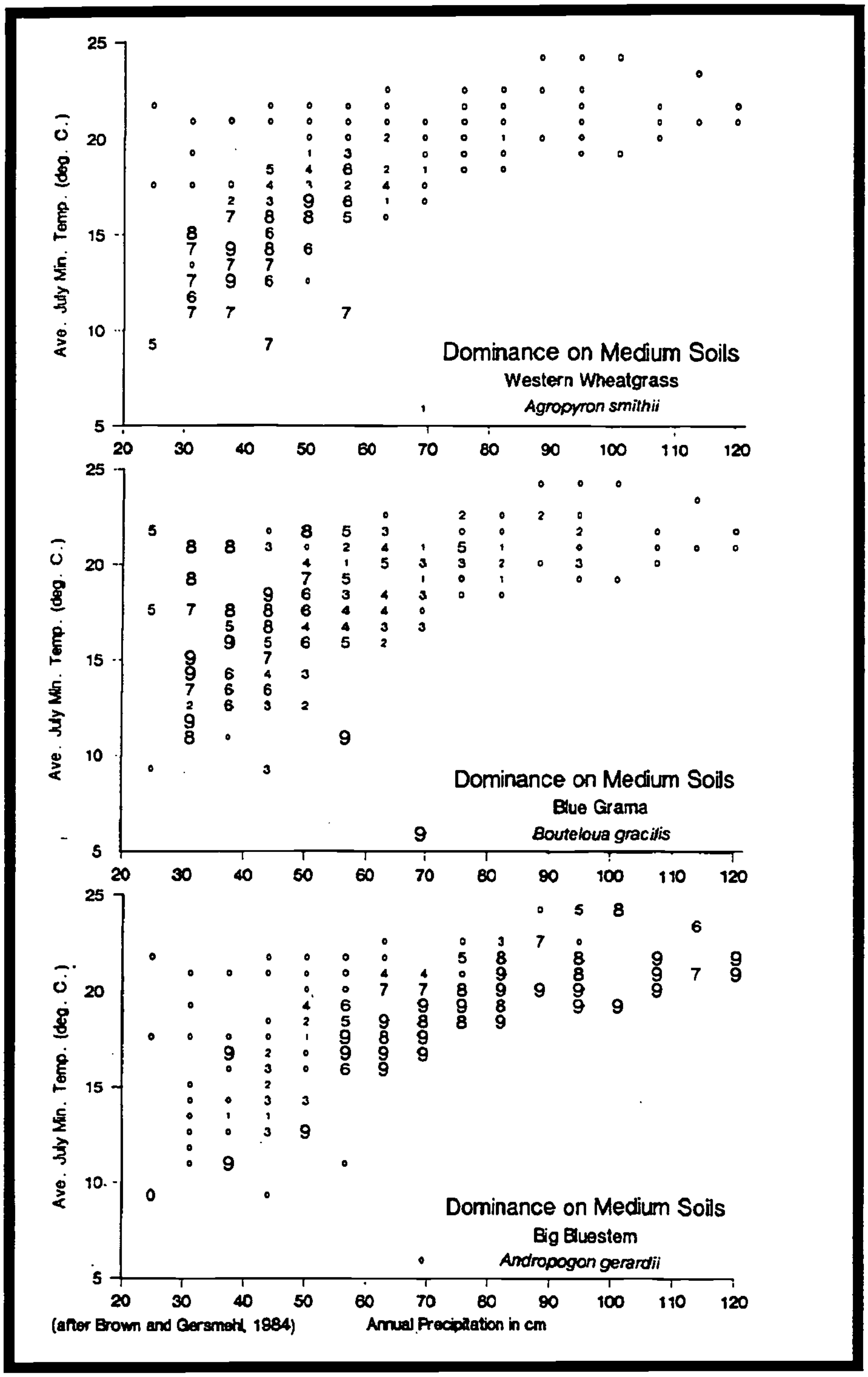

Figure 4. The relationships between dominance of three major Midcontinent Plains grass species and climate. The numbers show the importance of the species in counties. A 9 indicates a county with the species as dominant on upland loamy soils. A 0 indicates the species did not occur in sampled quadrats clipped by the Soil Conservation Service and reported in county soil surveys (Brown and Gersmehl 1984).

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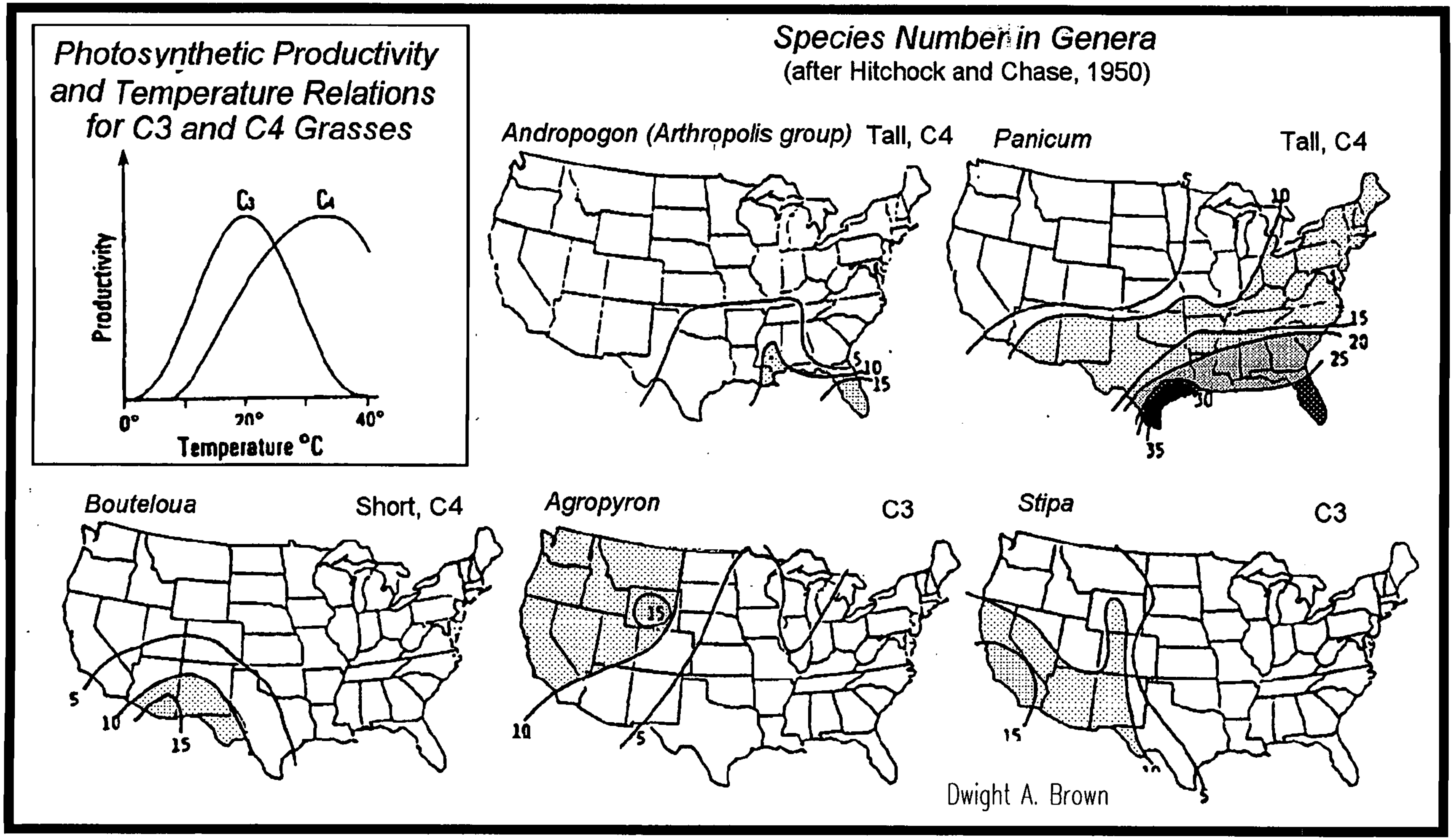


Figure 5. Geographic pattern of genetic diversity in major grass genera groups found in the Midcontinent Plains. The photosynthetic response of various grasses shown in the graph (upper left) are reflected in their geographies. Areas of high diversity may be major centers of dispersal. Maps plotted by author from data in Hitchock and Chase (1950).

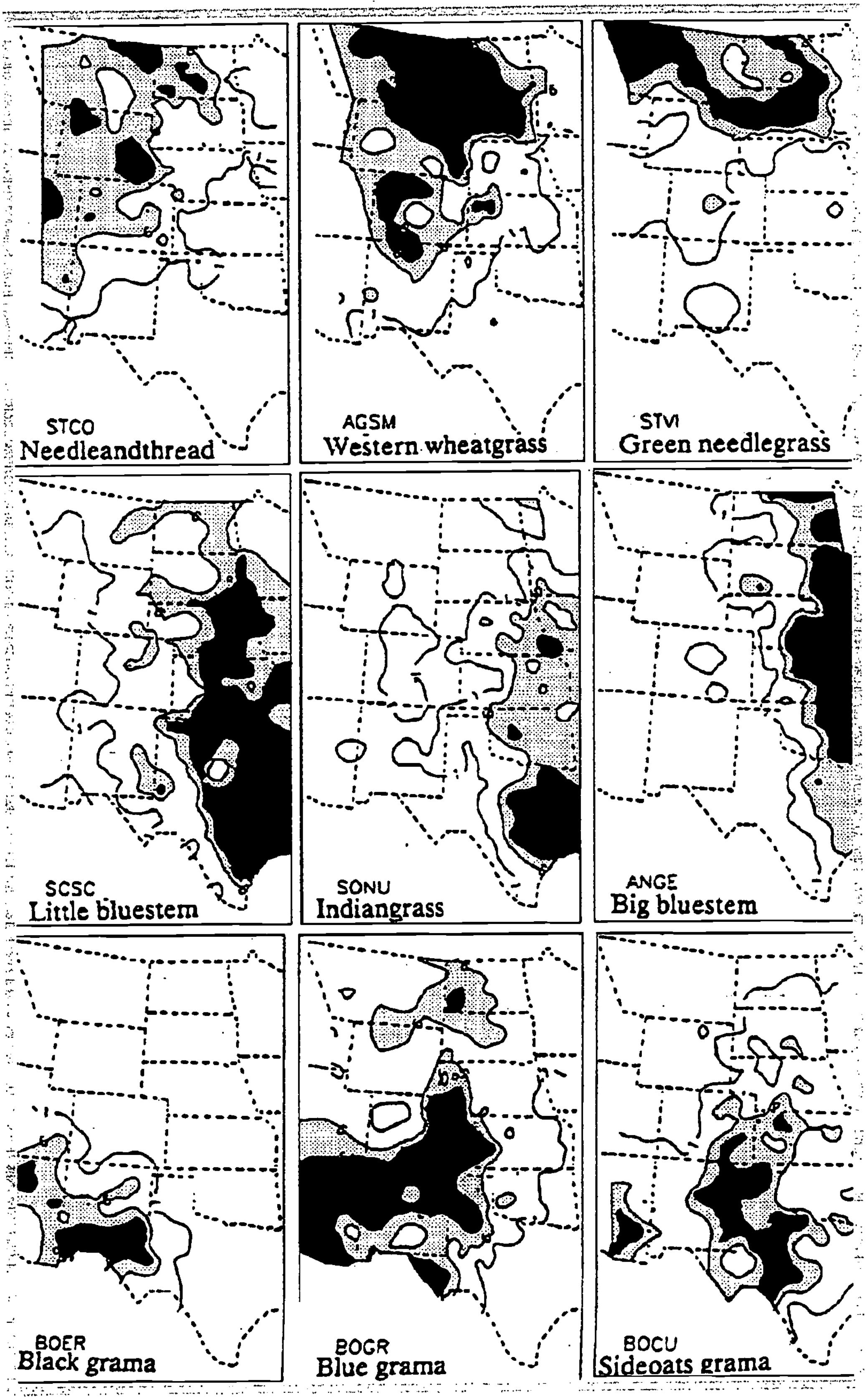


Figure 6. Relative abundance of major Midcontinent Plains grasses. Black is over 20% of biomass, gray is 10-20% and white areas inside the isoline have 5-10% of biomass.

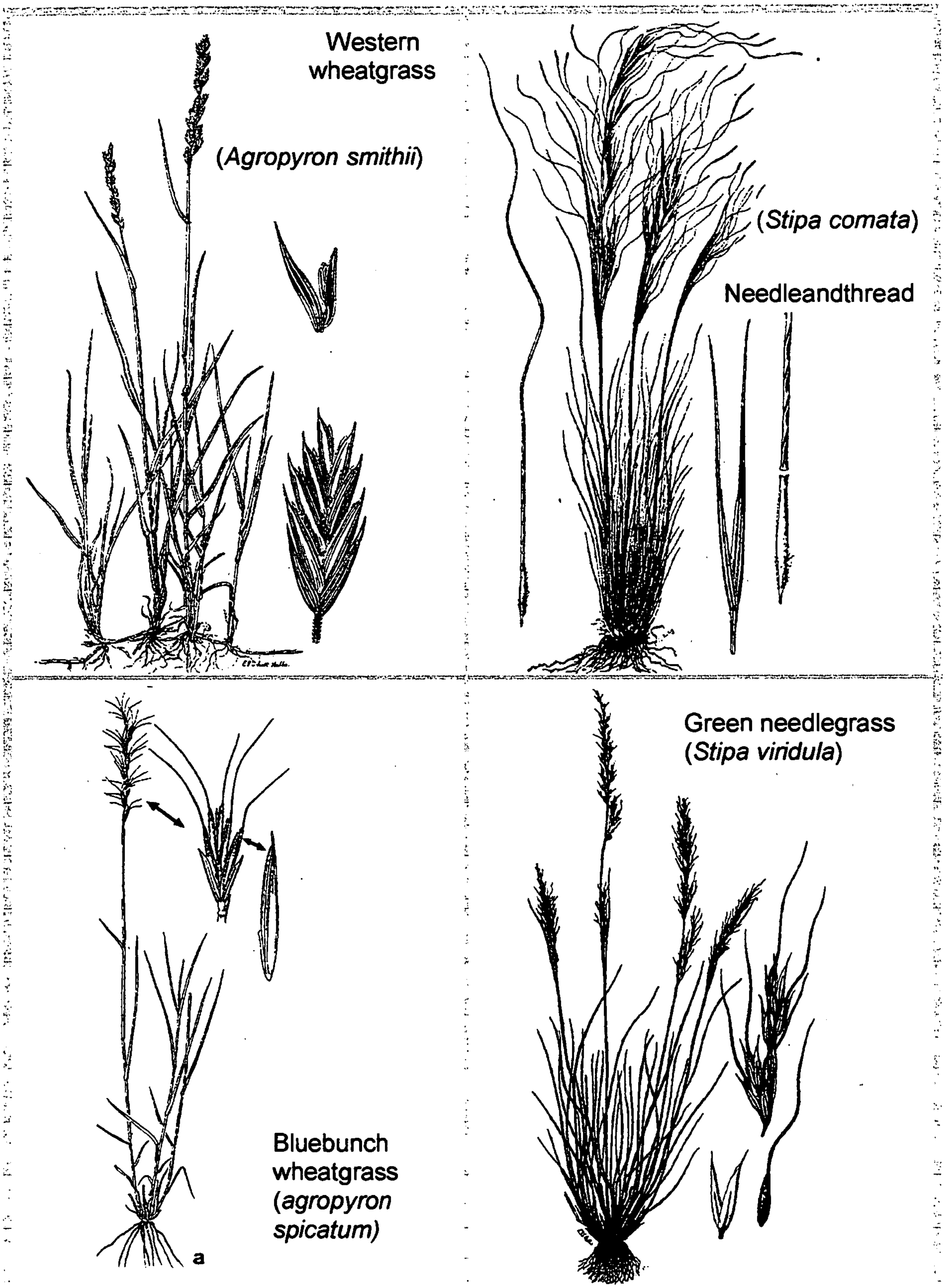


Figure 7. Morphologies of dominant cool-season (C3 photosynthesis) grasses of the Midcontinent Plains. Modified after Hitchcock and Chase (1950) by the author.

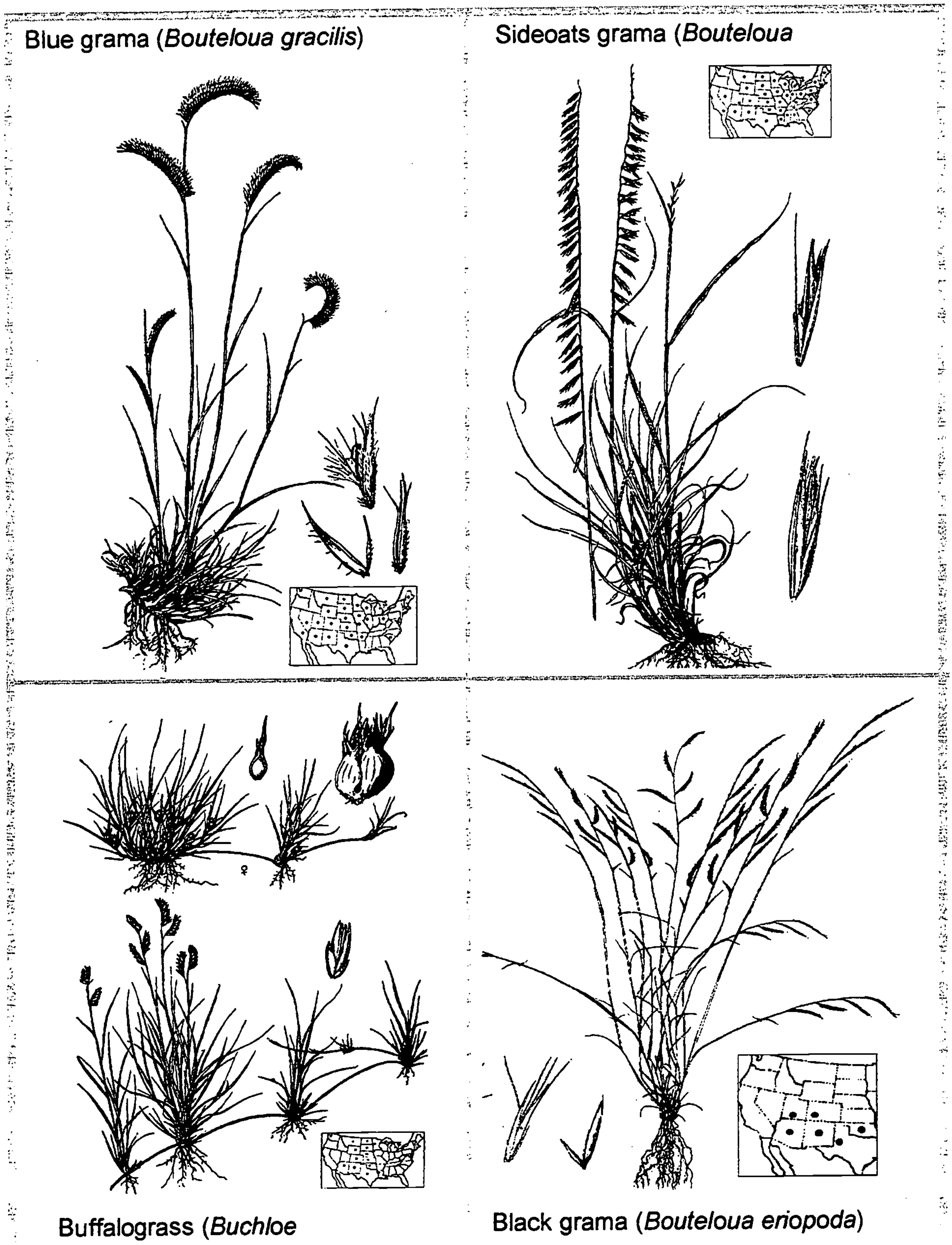


Figure 8. Morphologies of dominant warm-season (C4 photosynthesis) shortgrasses of the Midcontinent Plains. Modified after Hitchcock and Chase (1950) by the author.

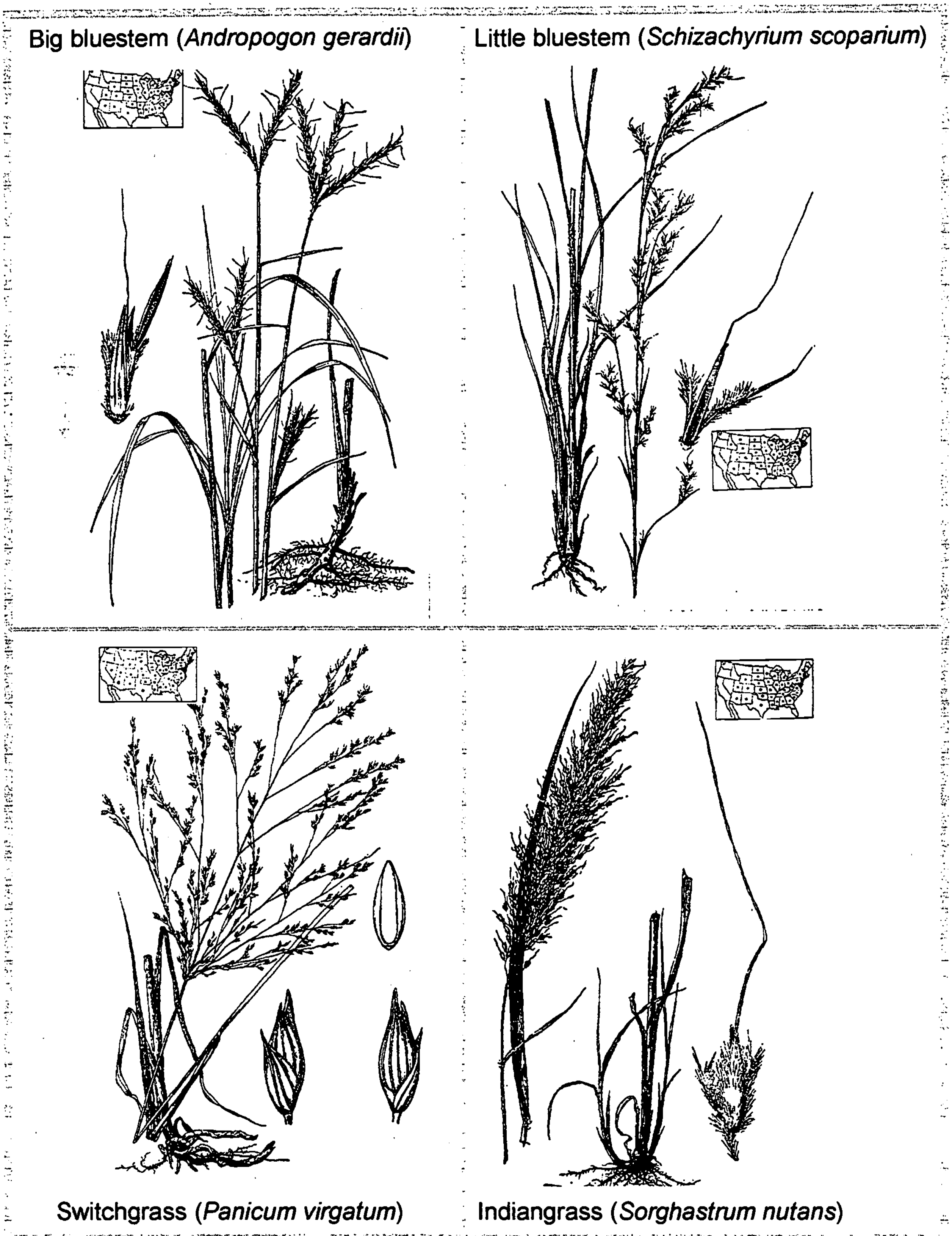


Figure 9. Morphologies of dominant warm-season (C4 photosynthesis) tallgrasses of the Midcontinent Plains. Modified after Hitchcock and Chase (1950) by the author.

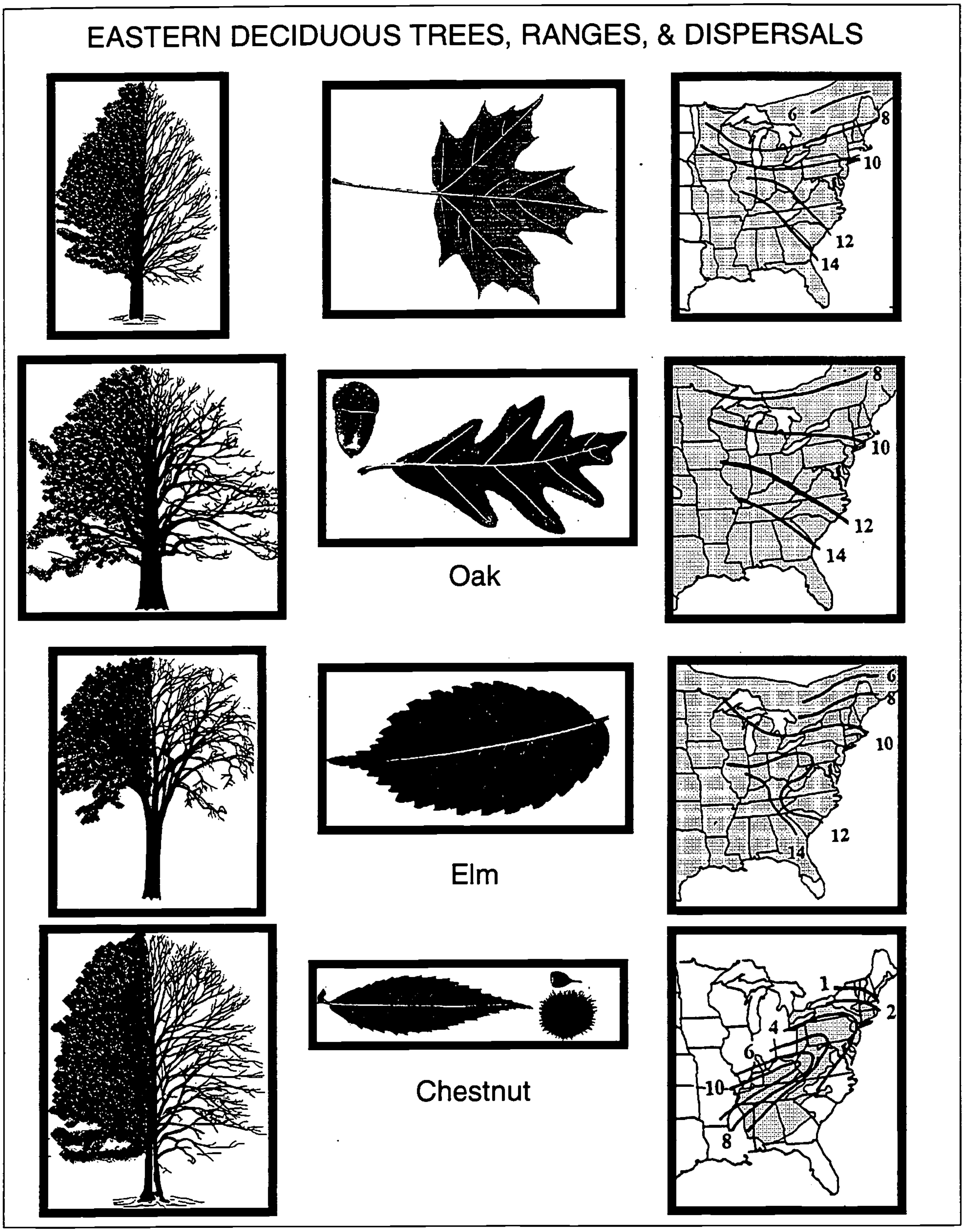


Figure 10. Eastern tree types and dispersal patterns since the last glacial maximum inferred from pollen analysis of sediments . Isolines represent first arrival times in 1000 years before present. Shaded areas on maps show modern range of tree types. Post glacial dispersal records based on pollen type analysis are after Davis (1983).

EASTERN CONIFEROUS TREES, RANGES, & DISPERSALS

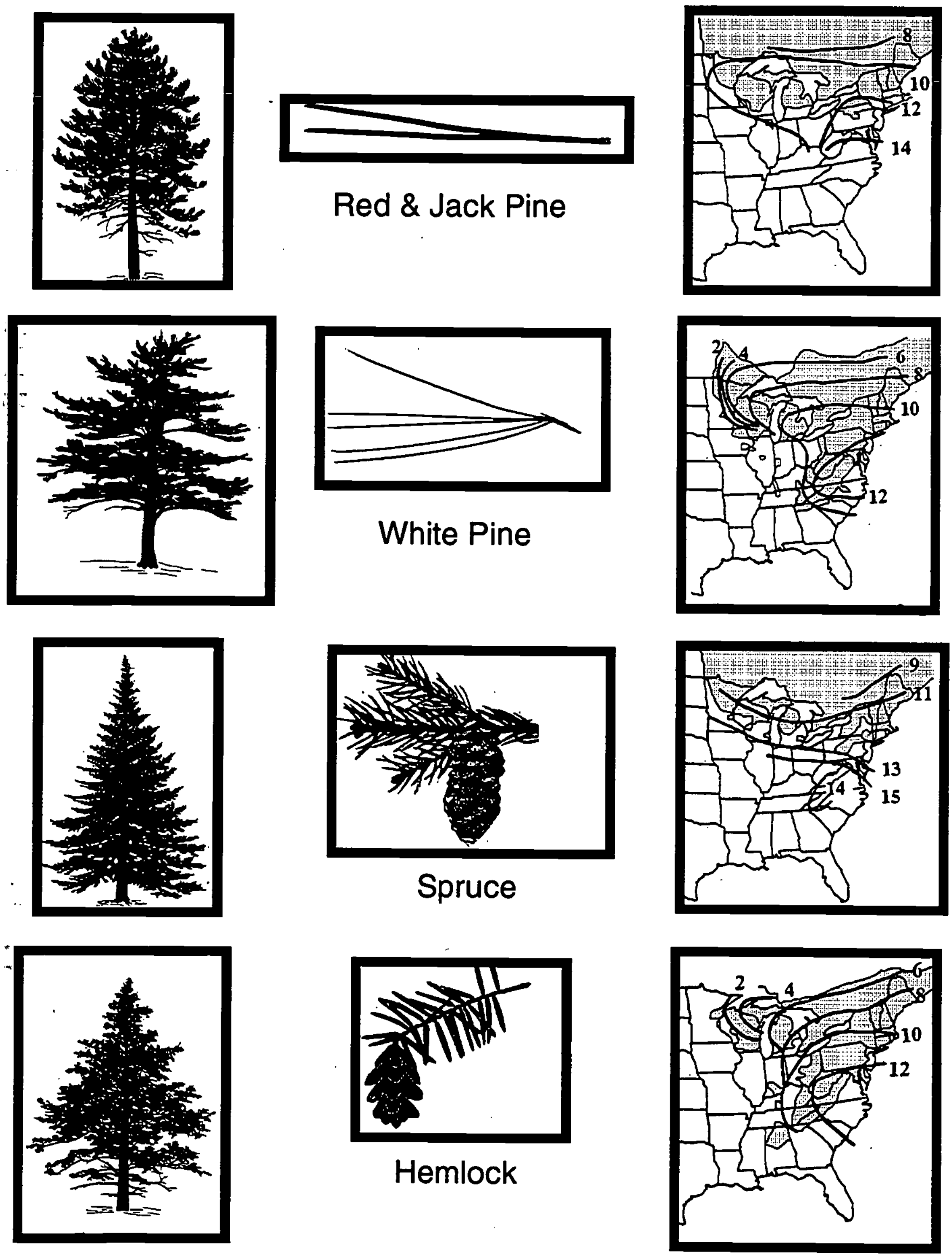


Figure 10, Continued. (1983).

MANAGING BIOGEOGRAPHICAL SYSTEMS

Humans interact with all the processes that create plant and animal population patterns. By modifying habitats and selecting desirable agricultural crops, humans affect processes of evolution, adaptation and extinction. We affect the patterns of genetic resources by creating disturbances that allow invasions, and by assisting and blocking dispersal. These actions facilitate both the removal and addition of species to affected areas. We change the environment of species by introducing grazing, by irrigating, flooding, and draining. We add fertilizer or energy to biological systems which changes the nutrient and energy cycles and, in turn, the productivity of a place.

Changing what genetic resources are available For plants to evolve, there must be a wide variety of genes available within an interbreeding population. Then natural selection acts to favor some gene combinations over others, depending on the particular environment in which individual plants attempt to grow. Selection forces include climate, pests, competitors, and people. For thousands of years, farmers have been selecting and favoring plants that carry traits desirable for food production. Some of these traits include:

- fruits or seeds that are too large to be dispersed by wind or animals,
- seeds that all ripen at the same time,
- seeds that remain tightly attached to the plant and do not fall before harvest,
- fruits without bitter or toxic compounds that repel pests.

From this list we can see that most food crops would not survive without humans to disperse their seeds and protect them from pests and competitors. However, the selection process reduces the genetic resources upon which to draw. (See the discussion of crop genetic diversity at the end of this section for further information.)

Changing patterns of genetic resources All species are at one time invaders. However, the invasions of some exotic species have been aided by humans, and these have been the subject of much concern. The Russian thistle or tumbleweed was an early, inadvertent introduction into the Plains. The sea lamprey into the Great Lakes, Eurasian milfoil, purple loosestrife, and the zebra mussel are some of the most publicized recent invaders into Minnesota. Fire ants are a significant pest in the Gulf Coast states. Despite all these notorious nuisances, no exotic species is so publicized as the African honey bee, first introduced into Brazil in 1957. Population growth and dispersal allowed it to gain a strong foothold north of the Rio Grande in 1993. Other organism invasions (besides our own species) of historic significance include the starling, the boll weevil, and the Dutch elm beetle (Figs 12 - 14). These same invasion processes are also well known in viral infections such as influenza, and the particularly serious invasion of the human immunodeficiency virus (HIV).

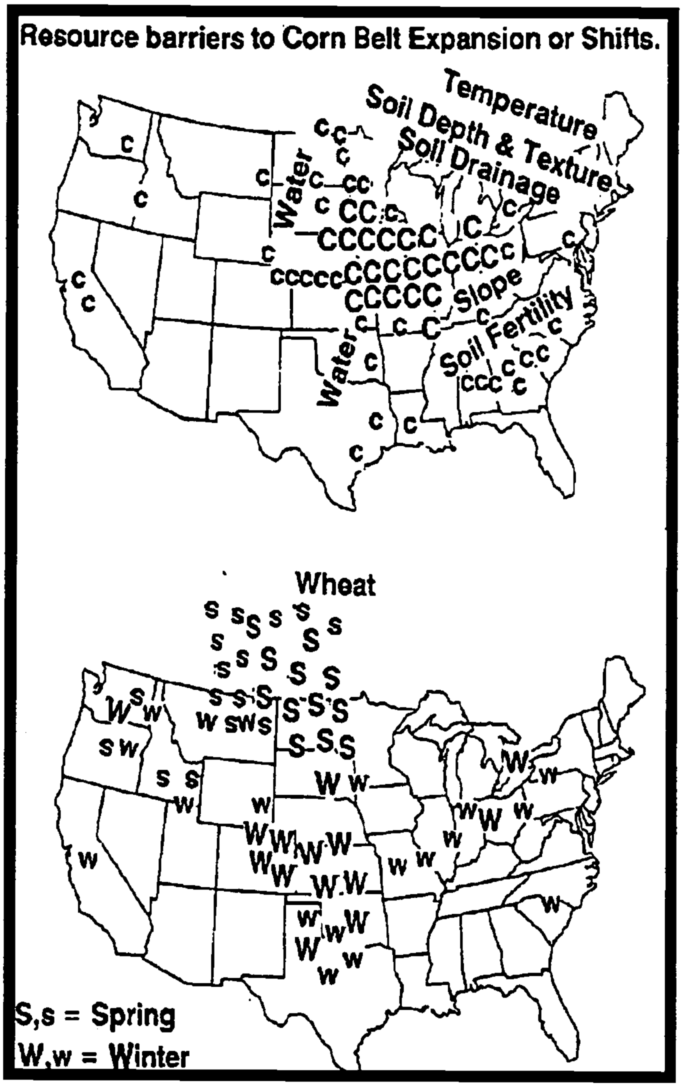


Figure 11. Corn and wheat crop regions of the US. Resource barriers to expansion or shifts in the corn belt are shown. Winter wheat is planted in the fall and goes dormant over winter. It has a head start over wheat planted in spring, which cannot be planted until the soil dries sufficiently for tillage equipment. That delay prevents use of the early season soil moisture. The earlier maturity or winter wheat allows it to mature before very hot weather, which harms yields of this domestic C3 grass.

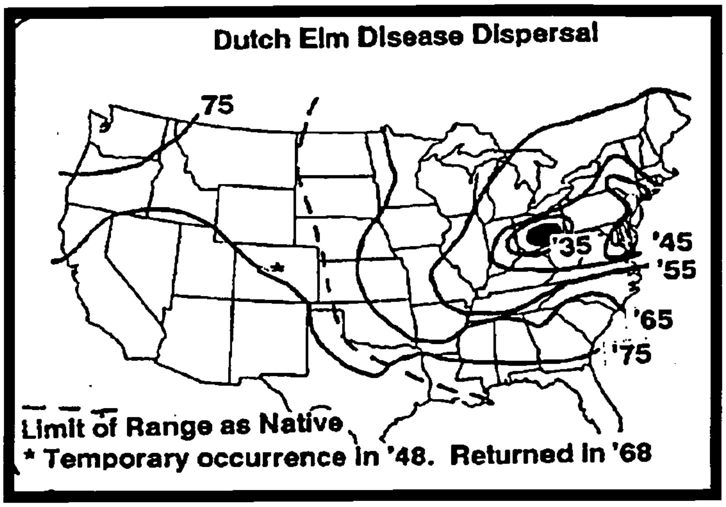
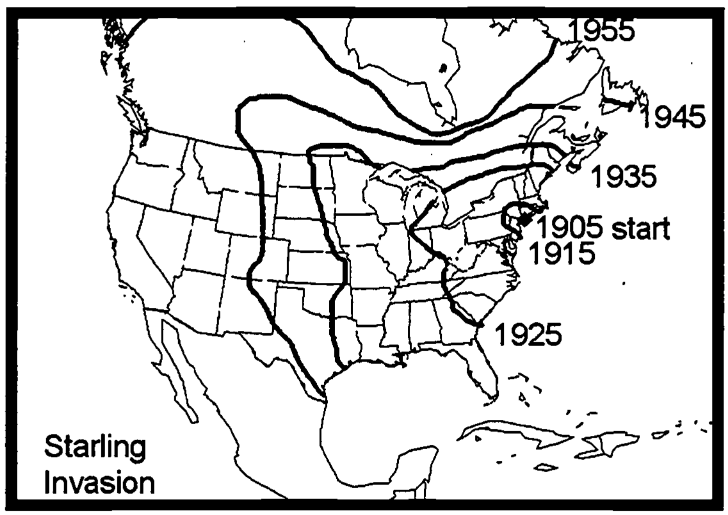


Figure 12.. The invasion of Dutch elm disease followed the dispersal of the Dutch elm beetle that carried the fungus.

Figure 13. It took only 50 years for starlings to spread throughout North America after their introduction from Europe in 1905.



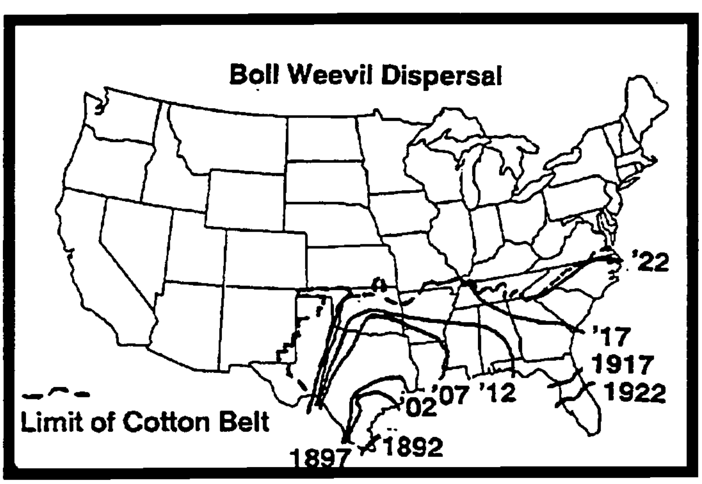


Figure 14. The boll weevil spread from Mexico through the old Cotton Belt in 25 years.

<u>Changing productivity of a place</u> Although we think about the questions of genetic resources, geographical pattern, and productivity as we consider the agricultural productivity of a place, attributes of place and economics are often govern the selection of what crops are grown where. Hence, not all crops are grown in their optimal location. For example, in Washington County Texas, grain sorghum is the optimal production crop on the Brazoria soil series. On the Norwood soil its production is just as high but the optimum crop here is corn. Neither are native plant populations distributed plants in a way that conforms with the places that best meet their needs for maximum production. Table 3 illustrates the effect of our emphasis on economic criteria for determining plant location. The table considers 3 plant types and 3 different places. Each plant occurs in each site. The economic value (see column headings with dollar sign) of its natural pattern is not the same as the optimal pattern for economic return. The price of plant 3 is such that it is the favored crop in all sites, even though it is not the optimum producer in any. The optimum producer in Site C is Plant 1. Their optima are coincident. The optimum plant for Site B is also Plant 1, but the optimum plant at Site 3 is Plant 2. In a the Real Production block, some plants are not distributed to produce the maximum. The production of the sites is genetically or population limited. That means that the right plants are either not there or there are not enough of them.

Table 3. Optimum production and economic return for plant resources in places with different site characteristics.

Crop/Value	Genetic Potential			Potential Economic Yield			Real Production			Real Economic Yield		
Site	1	2	3	$1	$2	$3	1	2	3	$1	$2	$3
A	2	3*#	4	2	6	12$	0	3	0	0	6$	0
B	7*	2	6#	7	4	18$#	6	0	0	6$	0	0
C	9*#	1	5	9	2	15$	0	0	4	0	0	12$

* Site's optimum plant. # Plant's optimum site. $ Site's Economic Optimum

The potential economic yield shows how land management would strive to move genetic material to optimize dollar return. If managers were concerned with maximum productivity, they would use plants indicated in the Genetic Potential Block.

These are monocultures. Greater long-term production is usually sustained at a higher level and at a lower energy cost when multiple plants grow together. Two factors are involved here, no energy is expended to keep the system simple (low weeding expense) and the different plants are not always in competition for the same resources at the same time. That means if resources, such as rain or solar radiation are available at different times and plants have different phenological calendars (their growth stages have different calendars), some plant is prepared to take advantage of the resource when others are not. The result is a more complete use of energy inputs and a greater total biomass production.

Types of Human Interactions with biological systems

1. Human interactions with biogeographical systems fall into four major classes of involvement: non-altering resource use -- e.g., low-impact leisure in agricultural landscapes,
2. sustainable resource use --e.g., agriculture that maintains soil productivity and water quality
3. exploitive resource use --e.g., agriculture or forestry practices that do not maintain soil and water quality,
4. destructive resource use --e.g., use of chemical pesticides and fertilizers in a way that damages soil and water quality or affect the food resources of other organisms; use of modified live viruses vaccines and antibiotics to kill epidemiological organisms.

Our objectives differ in each case and there are ranges of strategies used in each of these categories.

The last category of destructive human interactions highlights the point that not all biological systems are viewed as a resource. In some cases the term management means eradicating the organism. Have you developed the fear of shatter cane or velvet leaf that herbicide commercials attempt to instill in you? The herbicide brand name *Eradicane* obviously focuses on the idea of total elimination. Small pox or the polio virus are two examples of intentional eradication. A natural systems view would be that these organisms play a role in creating opportunities for other populations or organisms to use resources. From micro-organisms to humans to whales, death of the old creates opportunities for young of the same species.

Use of natural biological resources range from total exploitation, leading to extinction of species, to management efforts that attempt to maintain the productivity and yield of the system. These efforts usually focus on use of forest products or animal production by grazing range lands. In some cases the effort is directed toward restoration or rehabilitation of biological resources. This is a goal that cannot be accomplished because the boundary conditions that convey new genetic materials into the site are not restored. Wilderness areas are also managed to preserve wildlife habitat, plant resources, or plant patterns.

Agriculture is a direct and intentional attempt to control the dynamics of the biological system. The emphasis is on nurturing selected species. Yet, even here we control only a small part of the factors of production. For those factors we do not control--such as weather and genetic resources--we use game strategies, labor, and technology to mitigate them. In agriculture we may manage one or more trophic levels. The simplest example is cash crop farming which only attempts to control primary productivity. Other farmers feed their crops to livestock. Still others produce feed for dairy cows, sell cream or cheese, leaving skim milk or whey as byproducts to be fed to cattle, hogs, or chickens--the third trophic level. Maximum productivity of each level is controlled by the tax leveled by the necessary respiration and system maintenance of each level. If the population at one trophic level explodes in number, they must necessarily consume their resource base. That resource base depletion results in a crash of the consuming population (an example of the chaos theory model outcome). Biomass growth at each stage depends on the supply of nutrients beyond those required to maintain the system.

We use a number of strategies to mitigate threats to our goals of controlling biological systems and maximizing their production. At one extreme of the agricultural management spectrum is high technology farming, and the other end is nonmechanized farming that tries to mimic the optimum productive behavior of natural ecosystems. The former substitutes machines, plant genetics, and chemicals for labor. The latter, often practiced in the wet tropics, depends on high labor and substitutes land and time for fertilizer inputs by long periods of fallow that allow the natural system to restore nutrient levels and reduce pest populations. Sustainable agriculture as practiced in the Midwest falls between these extremes.

DEFORESTATION AND DESERTIFICATION

Introduction

Deforestation and desertification are two issues that are often linked, but are not synonymous. These environmental changes become issues because of concerns about their long-term consequences. *Deforestation* is the removal of trees without replacement.

Desertification is the devegetation of semiarid areas where the types of plants that were removed by over grazing or cultivation cannot reestablish themselves or it is the decrease in atmospheric moisture sufficient to kill plants, expose bare, soil and reduce water supply to plants, streams, and groundwater supplies.

Deforestation

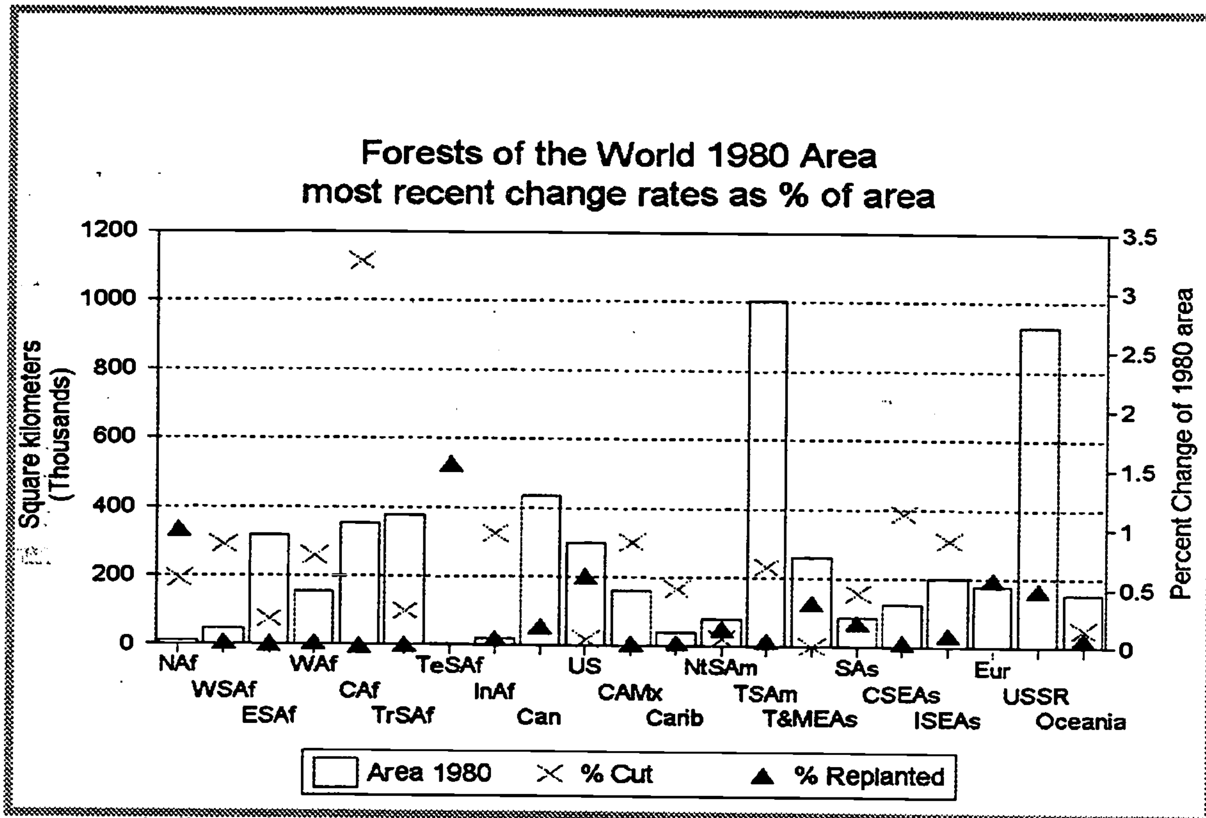
The primary deforestation concern in the media today is focused on the wet tropics. The purpose for most of the deforestation in the wet tropics is land clearance for small swidden agricultural plots and large farming operations (49%), commercial logging (26%), fuelwood (14%), and grazing (11%). The balance of these causes differs around the globe. Swidden agriculture (slash and burn) is responsible for 70% of closed forest clearing in tropical Africa, 50% in tropical Asia, and 35% in tropical Latin America. Expansion of cattle grazing is responsible for 30% of the Amazon Basin deforestation (World Resources 1994).

The issue of deforestation in the wet tropics has come into wide public view because of its link to the global warming issue (the release of carbon stored in plants into the atmosphere as CO_2), and its link to the biodiversity issue. In addition, deforestation leaves soils highly erodible soils exposed to the atmosphere in a climate of frequent and intense rainfall.

Global patterns of forests, deforestation, and reforestation are illustrated in Figure 14.. In some areas, particularly less developed areas, cutting rates far exceed planting rates. Who is responsible? Often the major economic powers provide the market for the timber and livestock grown on deforested land. While the stimuli to cut forests vary, the following social/institutional reasons have been advanced.

- Land policies allow large estate expansion, thus forcing new settlement by small holders into the forests.
- Policies also recognize cutting as one way of improving land to gain title.
- Many lesser developed nations fail to collect resource severance taxes sufficient to sustain the resource or encourage efficient use.
- Most of these same nations need exports because of their negative balance of trade and to service huge international debts.
- Urban economic growth has not been sufficient to support the rapidly growing populations. That stimulates the growth of farming, which requires more land.

What makes these cases of excess forest removal over reforestation an issue of such prominence? The answer can be found by looking at how forests function in



Areas indicated by bar labels

NAf	N. Africa	WSAf	W. Sahel Africa
ESAf	E. Sahel Africa	WAf	W. Africa
CAf	Central Africa	TrSAf	Tropical S. Africa
TeSAf	Temperate S. Africa	InAf	Insular Africa
Can	Canada	US	United States
CAMx	Central America & Mexico	Carib	Caribbean Area
NtSAm	Nontropical S. America	TSAm	Tropical S. America
T&MEAs	Temperate & Middle E. Asia	SAs	South Asia
CSEAs	Continental SE Asia	ISEAs	Insular SE Asia
Eur	Europe	USSR	USSR (former)
Oceania	Australia & S. Pacific Islands		

Figure 15. World forest resources and rates of change between 1980 and most recent data up to 1985. Data are from World Resources 1994.

the local and global environments, at the length of time needed for restoration to former functioning levels, and a series of sociological, economic, and political issues that govern, stimulate, or result from over exploitation of forest resources. Lets look first at the way systems function in the natural environment. We should also keep in mind the fact that tropical forests are not the only source of sequestered carbon lost to the atmosphere. The soils over extensive areas of the Midconinent Plains contained over 100 tons of carbon per acre prior to cultivation. Erosion and oxidation have depleted most of these carbon stores to less than half of their former level. In addition extensive midlatitude areas have also been deforested. The biomass lost per square kilometer is much less than in tropical forests, but the total area is very large.

The role forests play in the carbon cycle and its relationship to the issue of global warming induced by greenhouse gas increases is a major issue. The carbon cycle is not independent of nutrient cycles or the hydrologic cycle. Solar energy drives the photosynthesis process of the carbon cycle that converts atmospheric CO_2 to plant carbon and the nutrient uptake is conveyed by the hydrologic cycle. Both of these processes are limited by temperature extremes. All three of these cycles are shown in a simplified form in Figure 16. The ability of the soil to supply nutrients to the biomass is one of the controls on rates of forest regrowth. Nutrient uptake by plants is also limited by precipitation, growth stage, and plant characteristics.

Two environmental issues that focus on burning of tropical rainforests (**selva**) are the low ability of the soil to support rapid regeneration and the conversion of huge carbon stores the in standing biomass to atmospheric CO_2. Figure 16 shows general models of the carbon and nutrient cycles. The general nutrient budgets for several major ecosystems presented by Gersmehl (1976) are shown in Figure 17. The fluxes are quite large for the selva, except for the fallout. Burning creates a one-shot influx of nutrients to the litter (the ash is nutrient rich), but the efficiency of return and holding of these nutrients in the soil for prolonged uptake by regenerating plants is very low because of the high throughflow of water and the high iron and aluminum in the soil overly flocculate materials (nutrients are repelled and not bonded to soil particles, which allows them to be easily flushed). The soil nutrient reserves quickly succumb to relentless leaching.

Desertification

As we move toward the drier desert environment, the rate of nutrient uptake is reduced by the lack of water to carry the nutrients to the plants. As the trees and other vegetation are removed, the amount of biomass converted to CO_2 is not large, but the protection of soil and understory plants is lost. Without planting and nurturing new trees, the fuelwood supply is lost, but not all impacts are local.

Christopherson *(p. 643)* cites deforestation, overgrazing, erosion, improper soil water management, salinization of soils, and ongoing climate change as causes for desertification. He also shows the global extent of the degree of hazard of desertification. What is missing is the impact that desertification in these vulnerable areas has on the global climate, and on local populations. Some of these areas now support high populations, while others are sparsely populated. Deforestation taking place in the areas subject to desertification is primarily for cooking fuel.

Just as in the deforestation of the tropics, the issue here is also regeneration. Examine the nutrient flow diagrams for the drier areas to see why. Why is it so difficult to revegetate desertified areas? In what ways would expansion of desert areas change global climates?

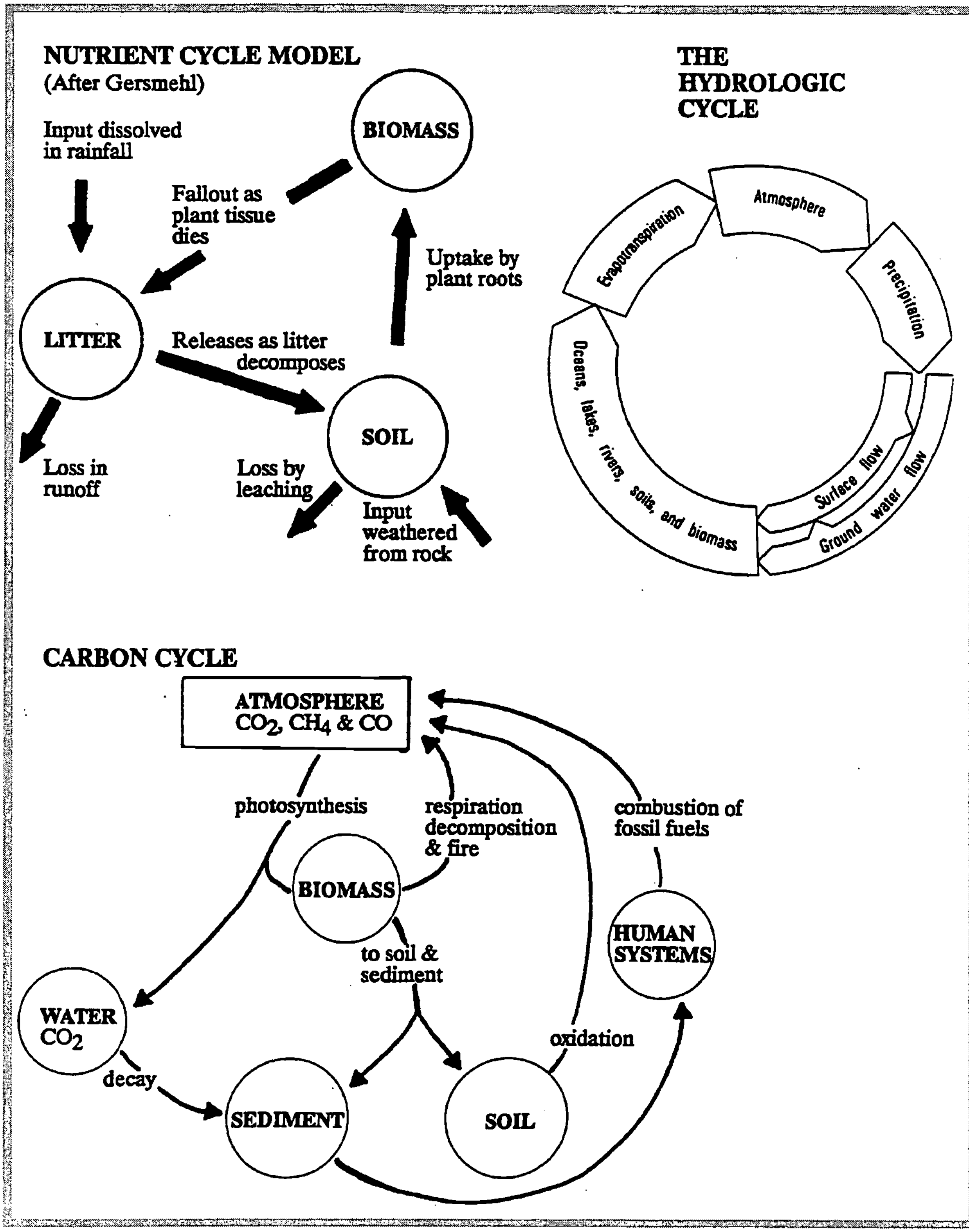


Figure 16. Environmental systems cycles. All of these cycles are mutually dependent.

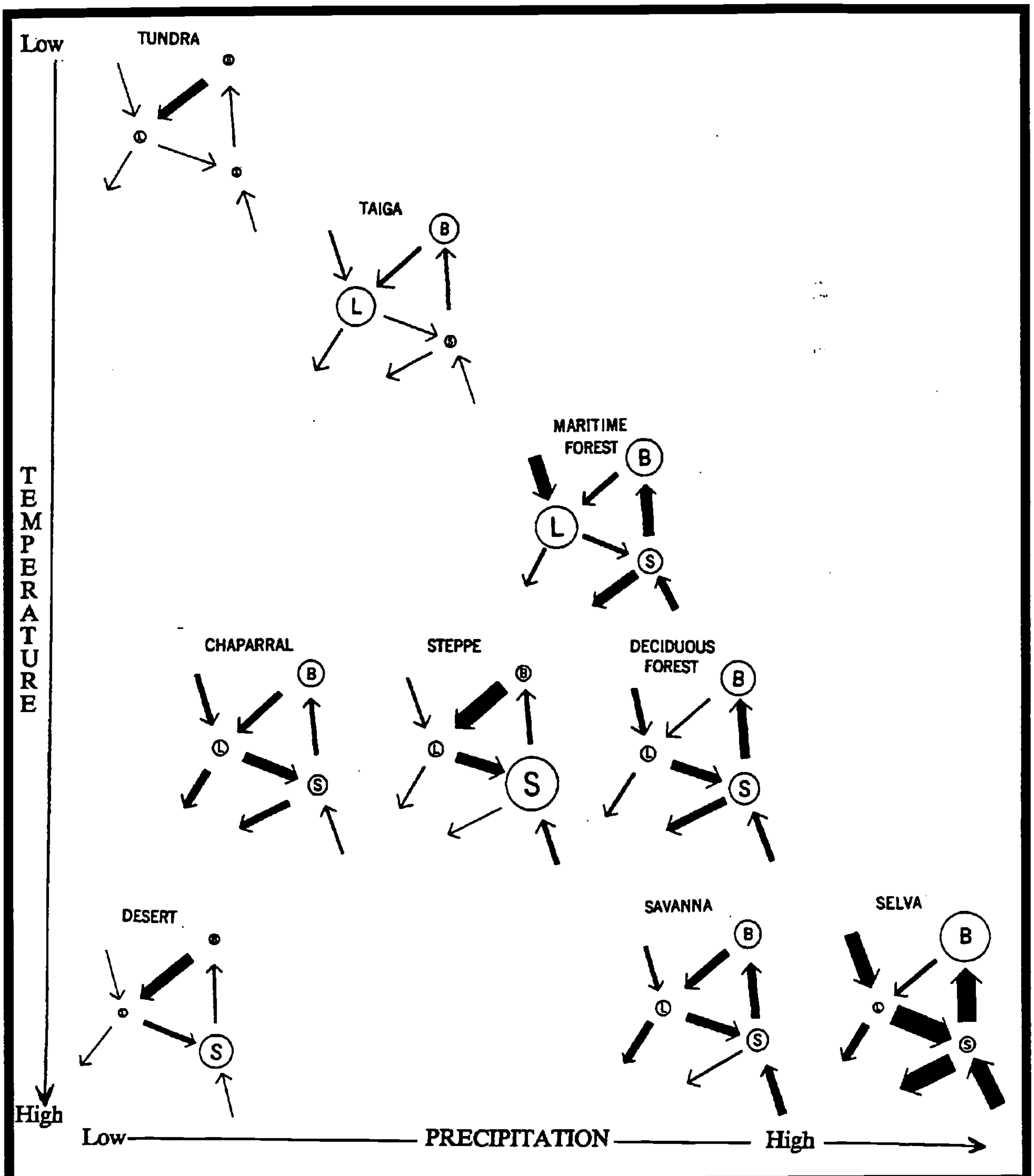


Figure 17. Nutrient cycling models for world biomes (after Gersmehl 1976).

CROP GENETIC DIVERSITY

by
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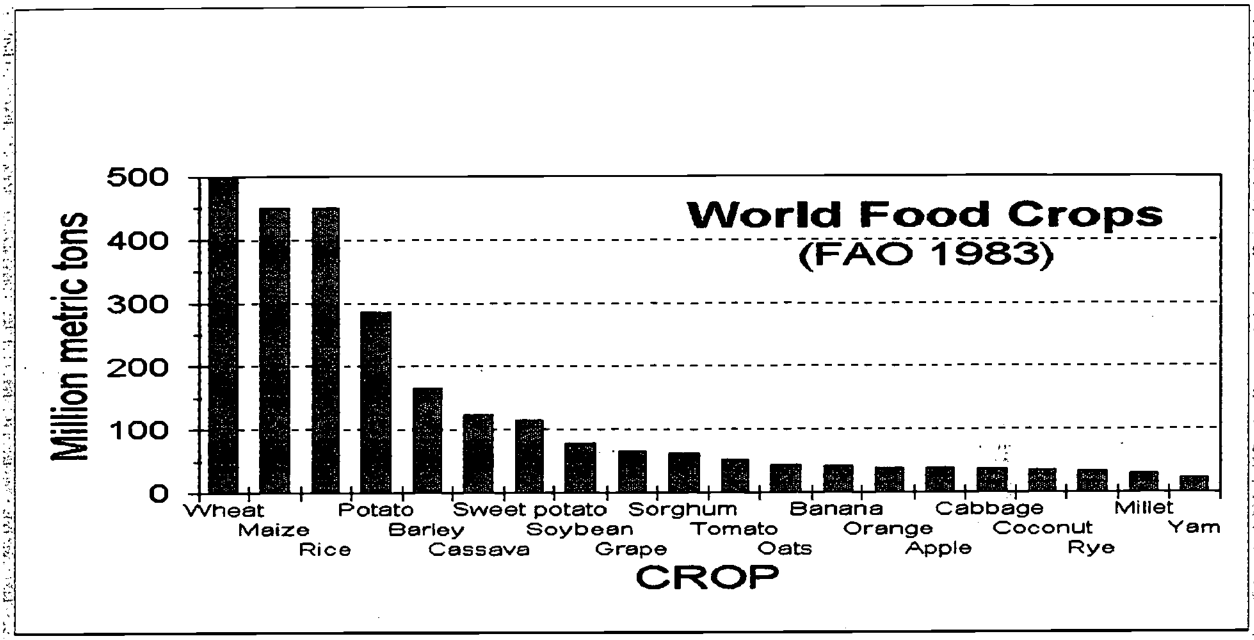
The crops grown in the world carry only a narrow range of characteristics drawn from the wide genetic base that evolved before agriculture. Some of the rejected characteristics were intentionally selected against because they reduced the growth, harvesting, palatability (agreeable flavor and texture), or cooking quality of the food. However, most of the loss of genetic material from the original pool was incidental to the selection process. Only a tiny fraction of seeds are preserved from one generation to the next. Those few seeds are selected based on only a small set of characteristics, and by chance might not contain some gene alleles (one of the two gene forms that inherited from each parent) that are present in the rest of the population. While unnoticed at the time, that lost genetic material may be useful at another time or another place for improving the food quality, hardiness, or pest resistance of a crop.

To compound the effect of the small genetic basis of each agricultural crop, our diets are based on only a small number of crops. Figure 18 shows 20 food crops and 20 industrial crops of highest production. Those food crops account for the vast majority of our nutritional needs.

The Russian botanist, N. I. Vavilov, hypothesized that the origin of a crop, where its wild ancestors evolved and where it was first domesticated, can be discovered by identifying the location of the greatest genetic diversity of that species. These centers of diversity are critical to our food supply because they hold the large pool of genetic material that was lost during the selection process. There are two pools of genetic material. One is that of the wild and weedy relatives of the crop. These genes are lost when their natural habitats are changed. The other pool, called landraces, is that held by the farmers whose ancestors domesticated the crop and who maintain wide varieties of a single crop for use under different landscape and weather conditions. These genes are lost when farmers switch to single, homogenous strains of crops.

The crops grown in the U.S. are carefully bred for high yields under high input conditions. The number of different genes existing in the nation's corn crop, for example, is a small fraction of those genes existing in related varieties in Mexico. To continue to improve productivity and to breed plants that are resistant to pests, plant breeders repeatedly look to the centers of diversity of the species to locate populations with desirable genes.

Kloppenburg and Kleinman (1987) divided the globe into regions and identified the region of genetic diversity for important crops (Table 4). Clearly, the globe's genetic



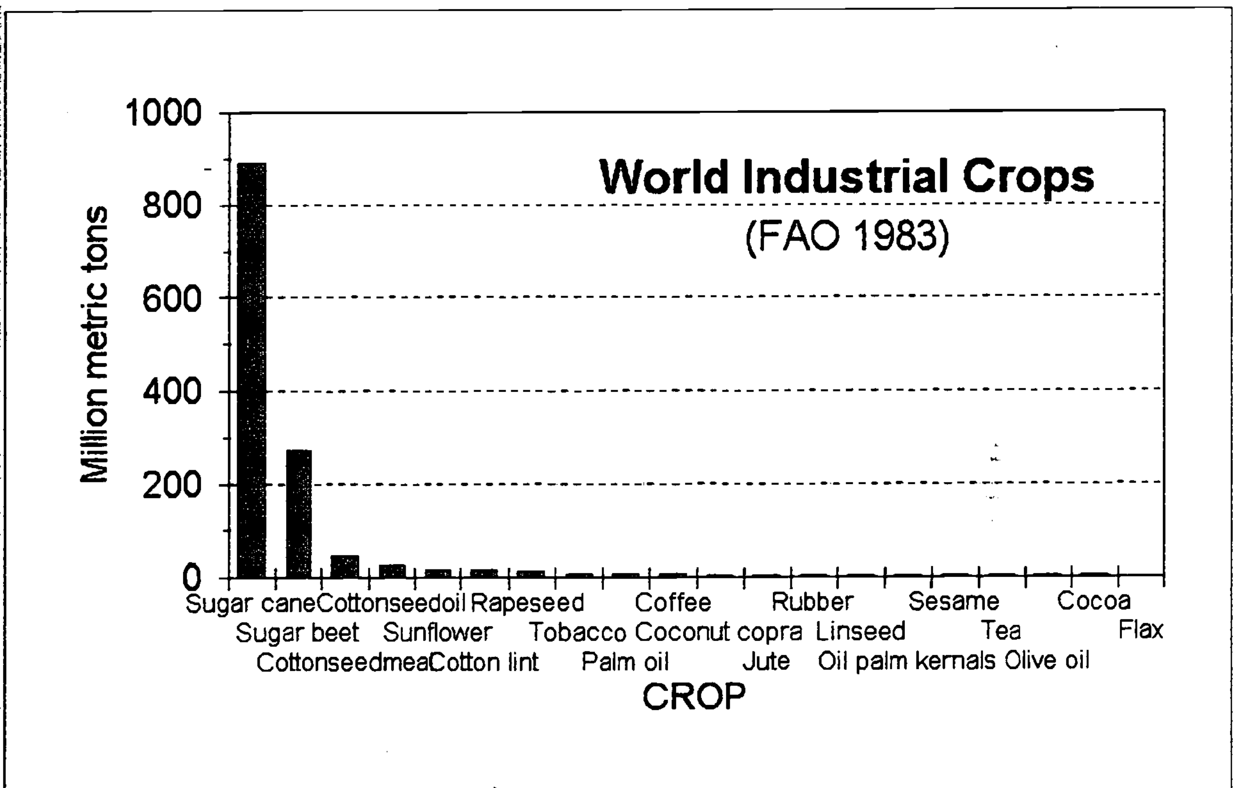


Figure 18. World agricultural food and industrial crop production (data from FAO 1983).

Table 4. Genetic diversity of important crops in their world source regions (after Kloppenburg and Kleinman 1987).

Region	Crops
Chino-Japanese	Soybeans, Oranges, Rice, Tea
Indochinese	Banana, Coconut, Yam, Rice, Sugar Cane
Australian	none
Hindustanean	Rice, Jute
West Central Asiatic	Wheat, Barley Grapes, Apples, Linseed, Sesame, Flax
Mediterranean	Cabbage, Sugar Beet, Olive, Rapeseed
African	Sorghum, Millet, Oil Palm, Coffee
Euro-Siberian	Oats, Rye
Latin America	Maize, Potato, Sweet Potato, Cassava, Tomato, Cotton, Tobacco, Rubber, Cocoa
North America	Sunflower

resources are not evenly distributed around the world. In the U.S., we have the technology to develop 'elite' crop lines and we have the resources to provide the large amounts of inputs needed to grow these crop varieties. Yet virtually our whole food system depends on the regular input of genes from other regions. Many plant breeders in the U.S. argue that genetic resources of wild plants and landraces are the common heritage of humankind and so should be freely accessible to all, especially since taking a few seeds for breeding does not reduce the supply of seeds. They also point out that their technology has led to high yield varieties (HYV) that have boosted yields in poorer countries.

Much of the world's crop genetic diversity is in economically poor countries. Many people in these countries argue that genes are a natural resource like any other and should be purchased from the country in which they occur. Genetic diversity is not maintained without cost. The habitat of wild varieties must be preserved and farmers must continue to grow and select their wide variety of landraces. Compared to elite lines, landraces tend to be more reliable and require less input of chemicals and irrigation, but they also yield less per hectare on average. Some governments have promoted the use of HYVs in order to improve their domestic food supply, but in the process, farmers have stopped growing the local varieties on which the breeding of HYVs depends.

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Potential Impacts of Climate Change on North American Flora

by
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Climate change is a natural phenomenon that has occurred throughout the history of the earth. The frequency and magnitude of climate change have varied substantially during and between glacial periods, and temperatures on both global and local scales have been both substantially warmer and colder than present-day averages (Ruddiman and Wright 1987; Pielou 1991; Peters and Lovejoy 1992). While potential magnitudes of local and global climate change are of concern, it is the predicted rate of temperature change that poses the greatest threat to biodiversity. The ability of species to survive rapid climate changes may partially depend on the rate at which they can migrate to newly suitable areas.

In the next few centuries climate may change rapidly because of human influences. The concentrations of "greenhouse" gases in the atmosphere are being altered by activities such as carbon dioxide emission from burning fossil fuels. Models of climate change (IPCC 1990, 1992) predict an increase in mean global temperature of about 1.5-4.5°C (2.7-8.1°F) in the next century. Temperature changes suggested by general circulation models would present natural systems with a warmer climate than has been experienced during the last 100,000 years. While this would be a substantial change from the current climate, the *rate* of climate change is the greatest determinant of the impact on biological diversity. Future climate change due to human influences could occur many times faster than any past episode of global climate change (IPCC 1990, 1992; Schneider et al. 1992).

The strong association between distributions of plant species and climate suggests that rapid global climatic changes could alter plant distributions, resulting in extensive reorganization of natural communities (Graham and Grimm 1990). Climate changes could also lead to local extirpations of plant populations and species extinctions. The effects of global climate change are likely to vary regionally, depending on factors such as proximity to oceans and mountain ranges. Alteration of the amount and timing of precipitation and evaporation would affect soils and habitats; freshwater ecosystems are likely to be vulnerable to these changes in hydrology (Carpenter et al. 1992). Even minor fluctuations in the availability of water can radically affect habitat suitability for many wetland plant species. Rapid, large-scale shifts in temperature, precipitation, and other climate patterns could have broad ecological effects, presenting major challenges to the conservation of biodiversity.

Analysis of Potential Effects

An analysis conducted by The Nature Conservancy on the potential effects of climate change on the native vascular flora of North America (Morse et al. 1993) provides a preliminary assessment of patterns of plant species' vulnerability. For this preliminary analysis, we made several simplifying assumptions about the relationships between plants and climate to estimate the viable climate "envelopes" for each of over 15,000 native vascular plant species in North America recognized in the checklist by Kartesz (1994).

The principal assumptions are that climate determines the range of plant species; mean annual temperature adequately approximates climate; species distribution appears to be in equilibrium with present climate; and a species' current climate envelope is equivalent to its tolerance of climate variation. Together, these assumptions state that the current distribution of each species is greatly influenced by climate and that temperature adequately represents climate.

Clearly, each of the above assumptions are not actually met for all native vascular plant species. For example, precipitation and soil moisture are extremely important determinants of range limits in some regions. These simplified temperature envelopes, however, allow the initial identification of broad patterns of species' vulnerability to climate change.

In the analysis, the mean temperature was uniformly increased in 1°C (1.8°F) increments up to an increase of 20°C (36°F) above current mean annual temperatures (Fig. 1). Many species would be vulnerable to climate change in all scenarios of uniform temperature increase. With a mean global warming of 3°C

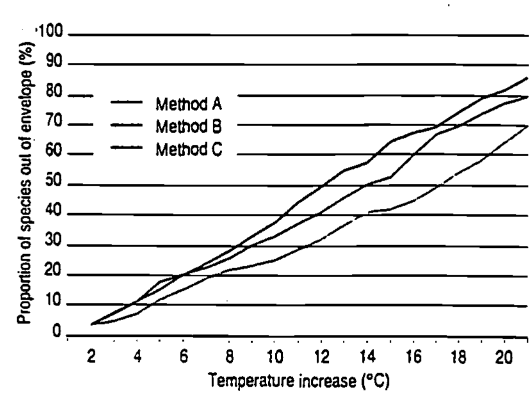

Fig. 1. The proportion of native vascular plant species that were entirely out of their climate envelopes as a function of the increase in temperature above mean annual temperature. Three methods were used to determine climate envelopes (A, B, C).

(5.4°F), 7% to 11% of 15,148 native vascular plant species in North America (about 1,060 to 1,670 species) could be entirely out of their climate envelopes. These species would thus be vulnerable to extinction unless they can migrate rapidly enough or can persist despite climate change. In comparison, about 90 plant species in North America are believed to have gone extinct in the last two centuries (Russell and Morse 1992).

Rarity and Vulnerability

Of the native vascular plant species studied, about 4,100 (27%) are considered rare by The Nature Conservancy (*see* article by Stein et al., p. 399, for definitions of ranking system for rarity). These species occur at fewer than 100 sites or are comparably vulnerable. Our analysis shows that these rare plants are likely to be further affected by climate change. In this analysis, about 10%-18% of the rare species would be vulnerable to a mean 3°C (5.4°F) temperature increase. In contrast, only 1% to 2% of the common species appear vulnerable under these conditions. These results imply that numerous rare vascular plant species could be additionally threatened by climate change. Early warnings of species' vulnerability to a rapidly changing climate might allow the development and implementation of new conservation strategies before a crisis occurs, thus improving the success rate for the protection of rare plants while minimizing the cost.

Regional Patterns of Vulnerability

Based on the uniform 3°C (5.4°F) mean increase in temperature used for this preliminary climate change impacts analysis, there appear to be regional patterns to the proportion of potentially vulnerable species in each state or province (Fig. 2). In this initially simplified analysis, the southeastern states have the highest percentage of species out of their climate envelopes, while the Great Plains states and provinces may experience proportionally fewer species losses. The relatively high proportion of species vulnerability in the Southeast may be due in part to the presence in state floras of Appalachian Mountain species at their southern range limits. Many of these species are already rare in states along their southern range limits and are likely to be lost from the local floras if the climate warms.

Global warming models, however, suggest that the temperature and precipitation changes in the interior of the continent will be far greater than in coastal regions. In the Great Plains, some models suggest increases in summer temperatures by 4-7°C (7.2-12.6°F), accompanied by dramatic decreases in precipitation. Future analyses that incorporate regional changes in climate projected by models will further refine our understanding of regional patterns of plant species' vulnerability to climate change.

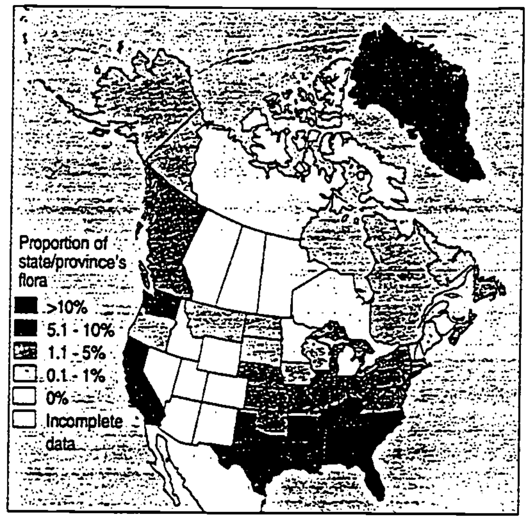

Fig. 2. The proportion of species that would be out of their climate envelope in each state or province with a +3°C (+5.4°F) temperature change.

Dispersal and Persistence of Vascular Plants

The survival of species during periods of changing climate will be determined in part by their abilities to disperse to new sites or to persist in place. For this analysis, a dispersal-ability scale was used to assess the potential for different species to migrate. The scale is based on characteristics important to species mobility such as pollination mechanisms, dispersal mechanisms, reproductive characteristics, degree of self-compatibility, growth form, trophic type, and number of populations. Biological factors likely to increase species mobility include wind pollination, at least partial self-compatibility, dispersal of propagules by wind or birds, and a short generation time. Characteristics such as dependence on specific pollinators (e.g., yucca and yucca moth), dispersal by ants, or a long generation time reduce the chances for successful rapid dispersal and establishment. By using these criteria, most of the species studied appear to have an intermediate dispersal potential.

The species in this analysis that would be vulnerable in a +3°C (5.4°F) climate appear to have characteristics that limit long-distance dispersal (Fig. 3). This suggests that the plants potentially most vulnerable to climate change may be those forced to adapt in place to new conditions. In general, rare plants and narrow endemics will be particularly endangered by climate change. These plants often have restricted ranges, a reduced seed source, and may depend on specific microclimatic conditions for

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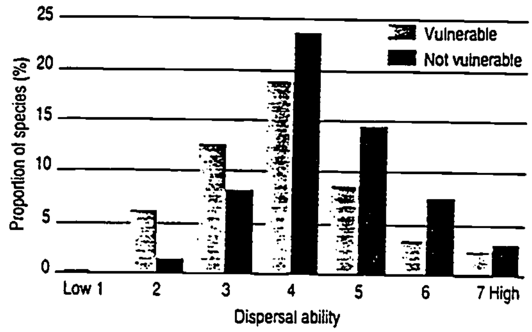

Fig. 3. The proportion of species on the dispersal-ability scale that are out of their climate envelopes (vulnerable) or in their climate envelopes (not vulnerable) with a +3°C (+5.4°F) temperature change. Full data were available for 8,668 species.

survival. Rare plants would thus potentially have trouble migrating to comparable new sites, regardless of their ability to disperse. For example, Boott's rattlesnake-root (*Prenanthes boottii*) and mountain avens (*Geum peckii*), endemic to alpine habitats in the northeastern United States, would be particularly sensitive to global warming.

Migration Rate

During the warming at the end of the last glacial period, plant migration rates, as calculated from the fossil pollen record, ranged from about 5 to 150 km (3-90 mi) per century (Shugart et al. 1986). Human-caused climate change may occur at rates more than five times faster than any changes since the last glacial maximum, including the period of most rapid deglaciation (Overpeck et al. 1991). Various studies have suggested that such rapid climate changes would require shifts of plant ranges of up to 500 km (300 mi) within the next century, exceeding the known rates of migration for many plant species (Davis 1984; Davis and Zabinski 1992).

Since species respond individually to climate change, migration rates will vary within and among natural communities. It is unlikely that entire biological communities would move together in response to climate changes (Graham and Grimm 1990). Some plants may respond rapidly to changes; others may survive for several generations in place or persist as long-lived clones despite significant climate change. The fossil record provides evidence of decade- or even century-long time lags in species migration (Davis 1989). The process of changing community composition in response to climate change has been documented in the fossil record through the disassociation and reassembly of plant and animal taxa (Graham and Grimm 1990). This variation in species assemblages displays the transitory nature of former as well as existing and future community types.

Temperature extremes and changes in the frequency and severity of local disturbances may have a greater influence on the survival of plant species at particular locations than small shifts in the average climate. More frequent droughts, fires, and pest and pathogen outbreaks are predicted to act in conjunction with climate change to significantly transform the landscape (Peters 1992). This prediction is supported by paleoecological evidence that altered disturbance regimes can intensify the effects of climate change on plants and increase the amount of overall vegetational change (Davis 1989).

Threats by Weedy Exotics

With global climate change, some exotic weeds may be favored over native species. Many weeds are able to expand relatively quickly, posing serious threats to existing species and overall biodiversity (Schwartz 1992). Many weedy species are widespread, prolific, fast-growing annuals capable of establishing in disturbed habitats and are often favored by disturbances. Climate-induced changes could expose native plants to nonnative competitors for the first time (Peters 1992), stressing the balance established between native plants and their habitat. Exotic weeds may become a greater problem in the management of many preserves and natural areas.

Landscape Fragmentation

The potentially rapid rates of warming, combined with habitat loss and fragmentation from human development, suggest that many species will not adjust as successfully to climate change as in the past. Most native plant species exist in a highly fragmented landscape that further separates appropriate habitat patches, increasing the dependence of many species on relatively rare events of long-distance dispersal. Furthermore, species often must disperse across hostile habitats, including roads, cities and suburbs, and farmland (Peters 1992). Finally, plants would need to establish themselves in landscapes where many of the open or disturbed areas have been colonized by aggressive weedy exotics.

Climate Change and Conservation Planning

Rapid climate change could place novel demands and constraints on plant species conservation. Vulnerability to climate change could affect selection and design of new preserves and management procedures in existing preserves, especially in southern or low-elevation portions of species' ranges. Management of species threatened by climate change could involve restoration and transplantation of species among preserves or into new locations. Actions such as removal of exotic species or hydrological controls may not be qualitatively different than those that are currently required of land managers, but climate change may increase the intensity and frequency of threats from exotic species, drought, and fire. In view of the unpredictable and potentially devastating effects of global climate change on species' viability and distribution, conservation strategies such as propagation of critical species outside of their natural range to provide materials for reintroductions are likely to become increasingly important to preserve biological diversity.

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