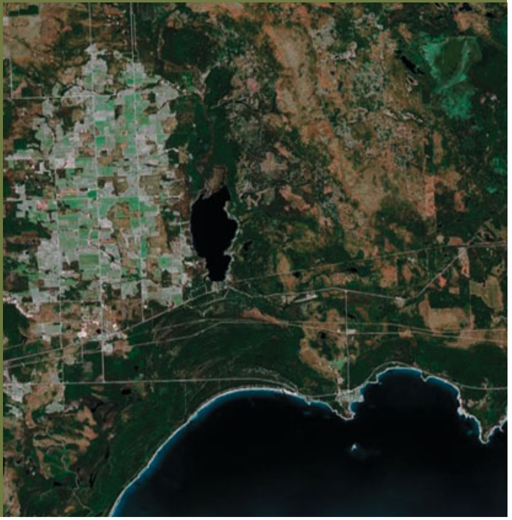
23

Landscape Ecology and Ecosystem Management



- *Case Study*: Wolves in the Yellowstone Landscape
- Landscape Ecology
- Habitat Fragmentation
- Designing Nature Reserves
- Ecosystem Management
- *Case Study Revisited*
- *Connections in Nature*: Future Changes in the Yellowstone Landscape

Case Study: Wolves in the Yellowstone Landscape

Figure 23.1 A Top Predator Returns

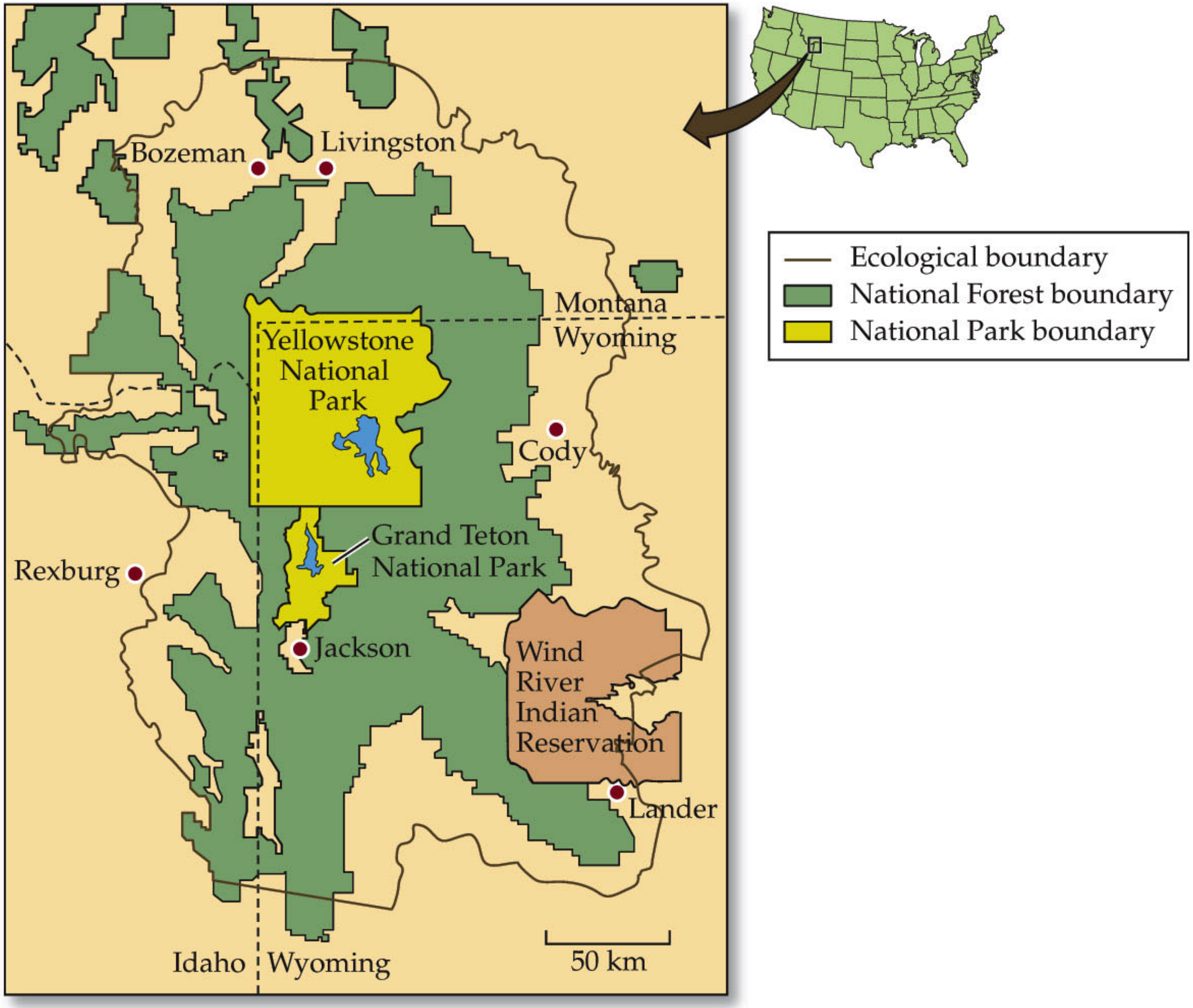
Wolves, absent from Yellowstone National Park for 70 years, were reintroduced in 1995.

Case Study: Wolves in the Yellowstone Landscape

The reintroduction involved years of research, much policy discussion, and was strongly opposed by some residents.

The Greater Yellowstone Ecosystem (GYE) highlights the challenges of managing public lands.

Figure 23.2 The Greater Yellowstone Ecosystem



ECOLOGY, Figure 23.2

The region is managed by more than 25 different state and federal agencies as well as private corporations, non-governmental organizations, and private landowners.

Decisions about land use and resources are complex. They can determine which species will be maintained, and which will not.

But the GYE is one of the most intact ecosystems in North America.

There are 7 species of native ungulates and 5 large carnivores.

After wolves were eradicated in the mid 1920s, there was concern that elk were overgrazing meadows. Until 1968, elk were regulated by culling.

Case Study: Wolves in the Yellowstone Landscape

In 1968, a new policy of “natural regulation” was implemented, and the elk population nearly quadrupled in 30 years, with subsequent decline of the plants they feed on.

Reintroduction of wolves has reduced the elk population, but has also affected the populations of many other species.

In the 1950s, beavers became scarce in the park, due to elk feeding on their preferred food plants, willow and aspen.

A whole suite of other species that depend on beaver ponds had declined along with the beavers.

The decision to eradicate wolves had not anticipated these ecological changes.

Introduction

Looking at ecology from a landscape perspective has been made possible by tools that permit us to view and sense the environment at many scales.

Aerial photography gave ecologists the means to look at “the big picture.”

Introduction

Remote sensing satellites now provide images of Earth that have vastly expanded the interpretation of large-scale ecological patterns.

Geographic information systems (GIS) have become standard for use in landscape planning, for conservation and urban development.

Figure 23.3 Geographic Information Systems Integrate Spatial Data from Multiple Sources (Part 1)

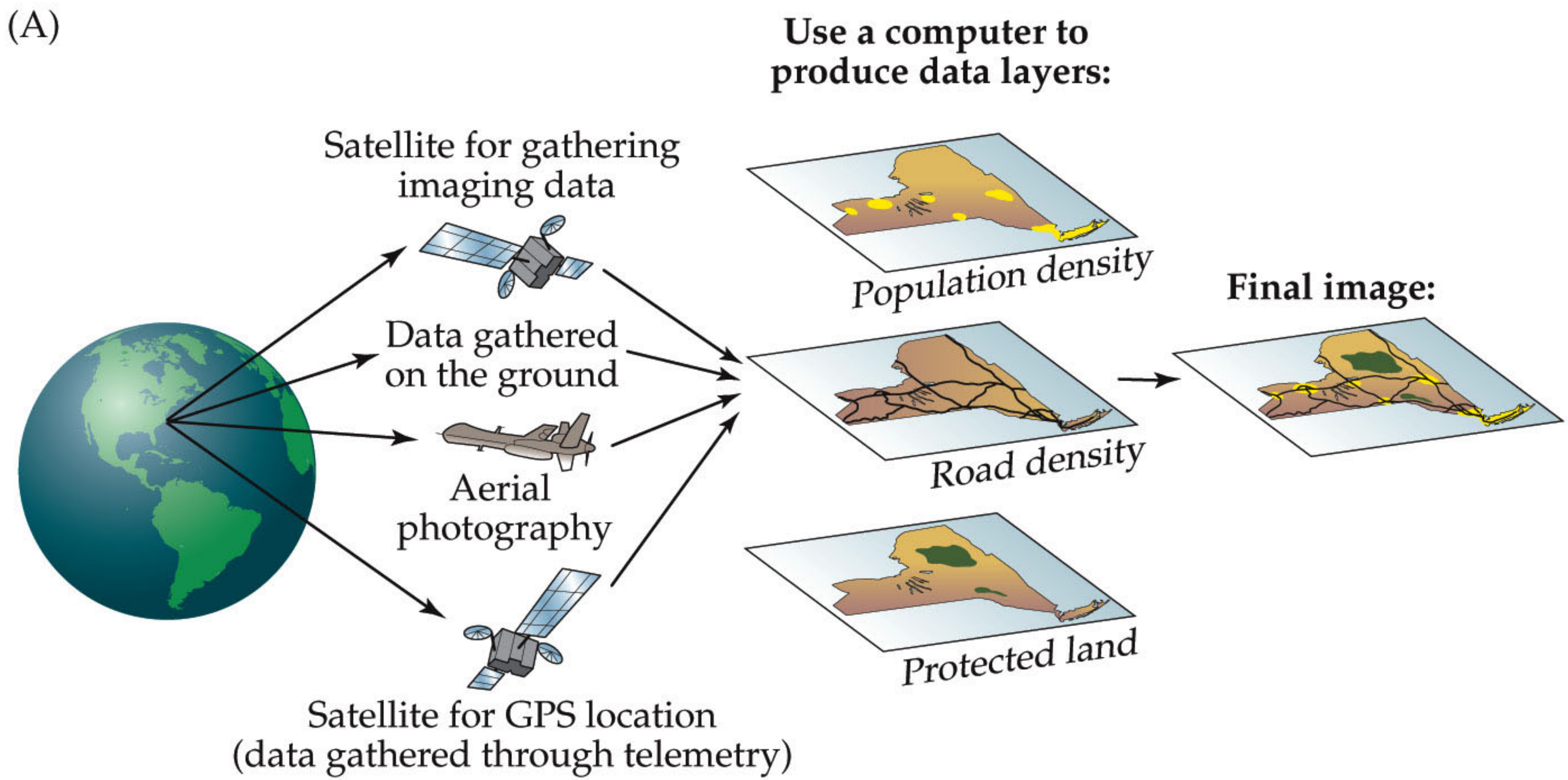
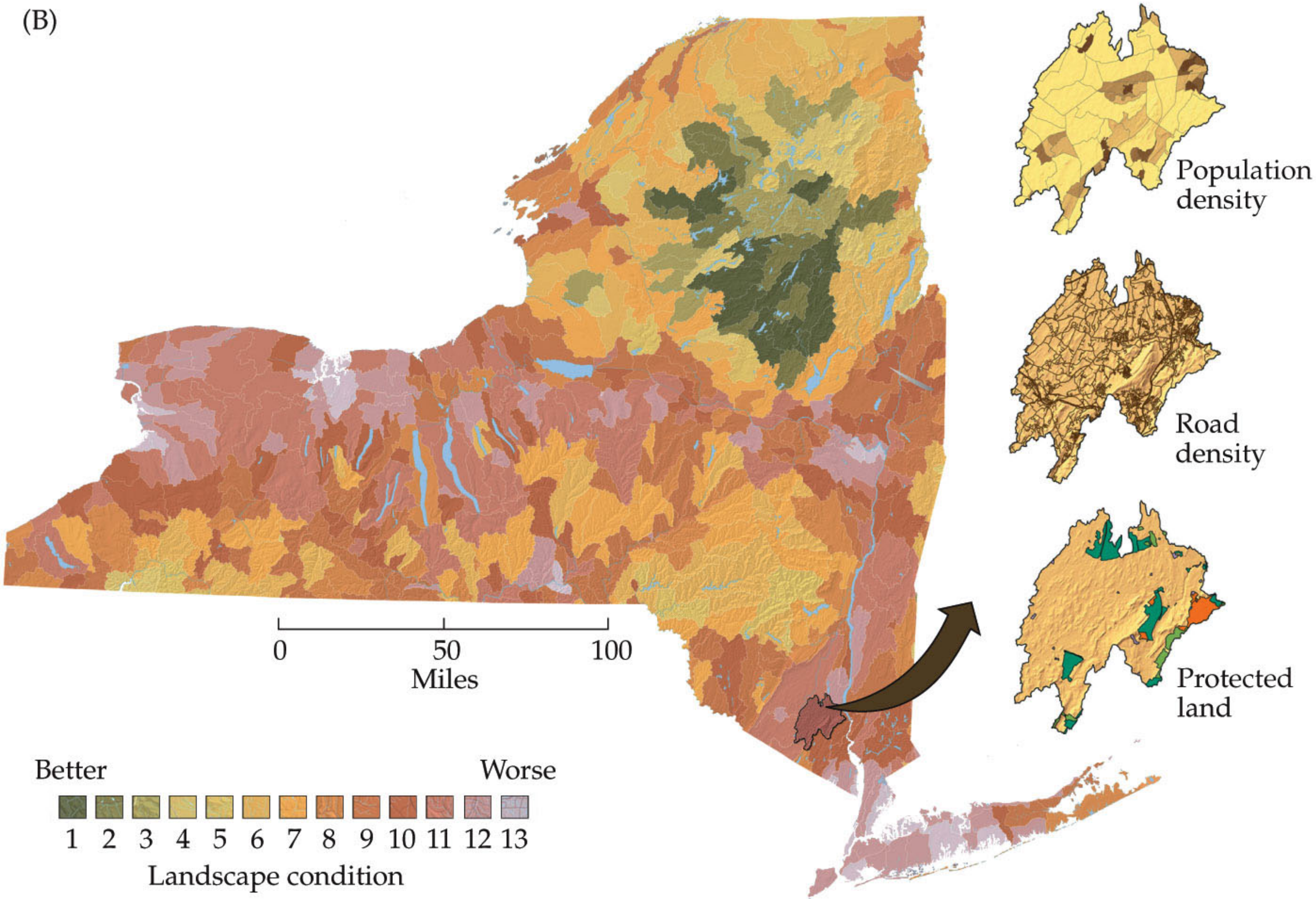


Figure 23.3 Geographic Information Systems Integrate Spatial Data from Multiple Sources (Part 2)



***ECOLOGY*, Figure 23.3 (Part 2)**

Introduction

In the field, global positioning systems (GPS) permit ecologists to document precise locations and integrate them with other variables through GIS.

Radiotelemetry allows us to follow animal movements and migration patterns, again with the help of GIS.

Data analysis improves with better computers and statistical methods.

Concept 23.1: Landscape ecology examines spatial patterns and their relationship to ecological processes and changes.

Landscape ecology—a sub-discipline of ecology that emphasizes the causes and consequences of spatial variation across a range of scales.

Landscape Ecology

Landscape ecologists look at the spatial arrangement of different *landscape elements* across Earth’s surface, and how those patterns affect, and are affected by, ecological processes.

Landscape—an area in which at least one element is spatially heterogeneous.

Heterogeneity can relate to types of landscape elements, or in the way the elements are arranged.

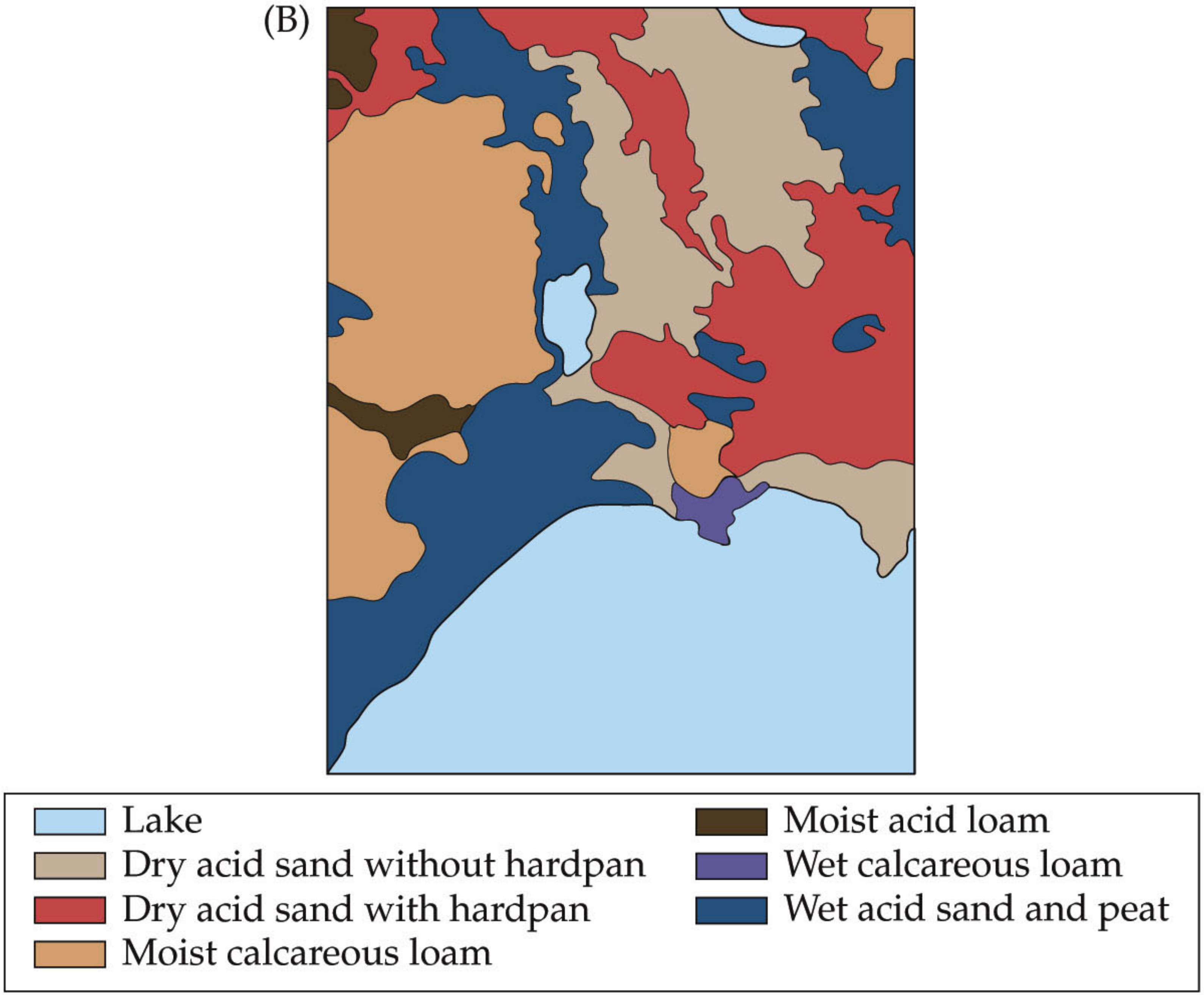
A **mosaic** is composite of heterogeneous elements.

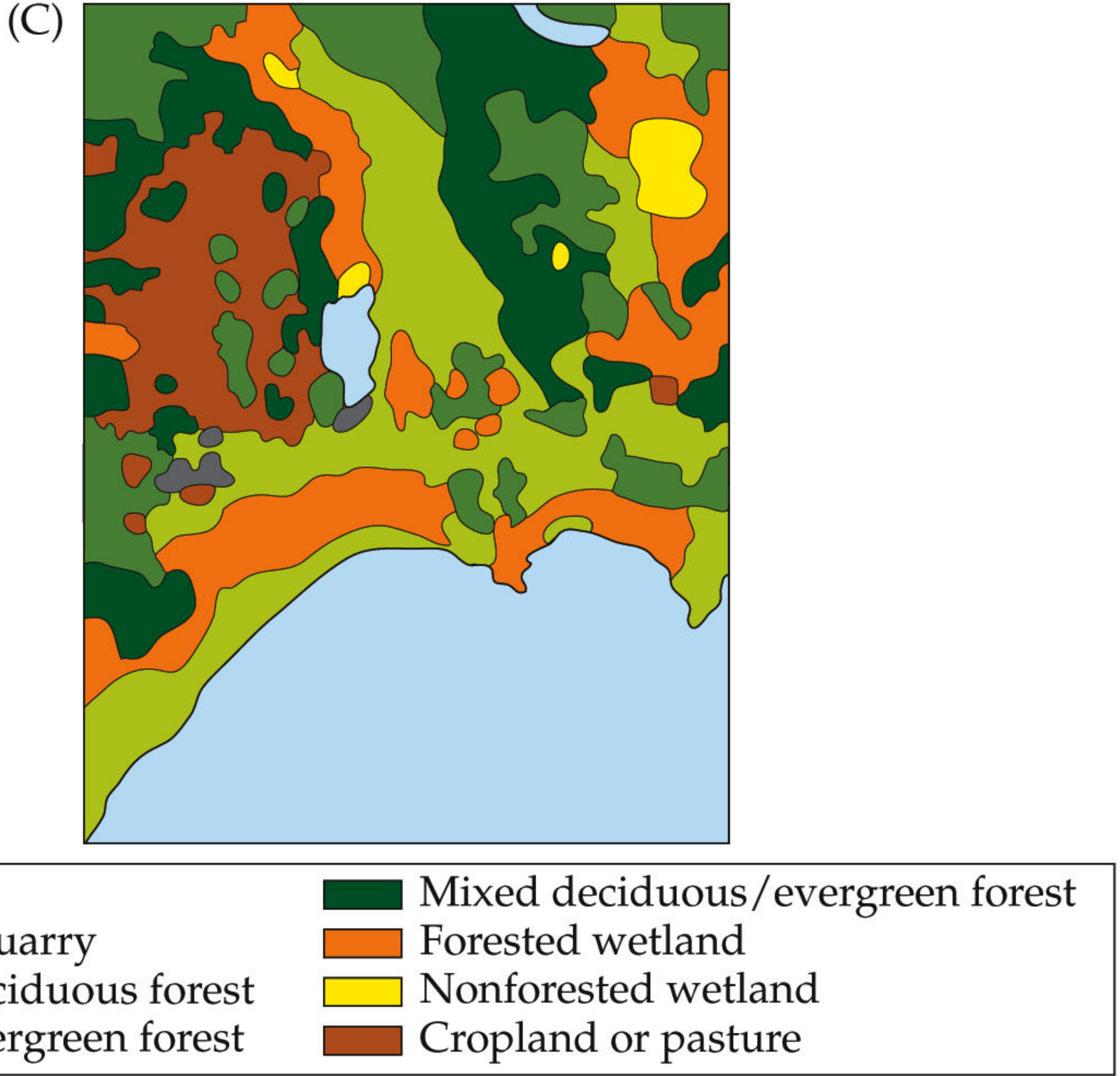
Figure 23.4 Landscape Heterogeneity (Part 1)

(A)

ECOLOGY, Figure 23.4 (Part 1)

Figure 23.4 Landscape Heterogeneity (Part 2)




(C)
Lake
Urban or quarry
Upland deciduous forest
Upland evergreen forest
Mixed deciduous/evergreen forest
Forested wetland
Nonforested wetland
Cropland or pasture

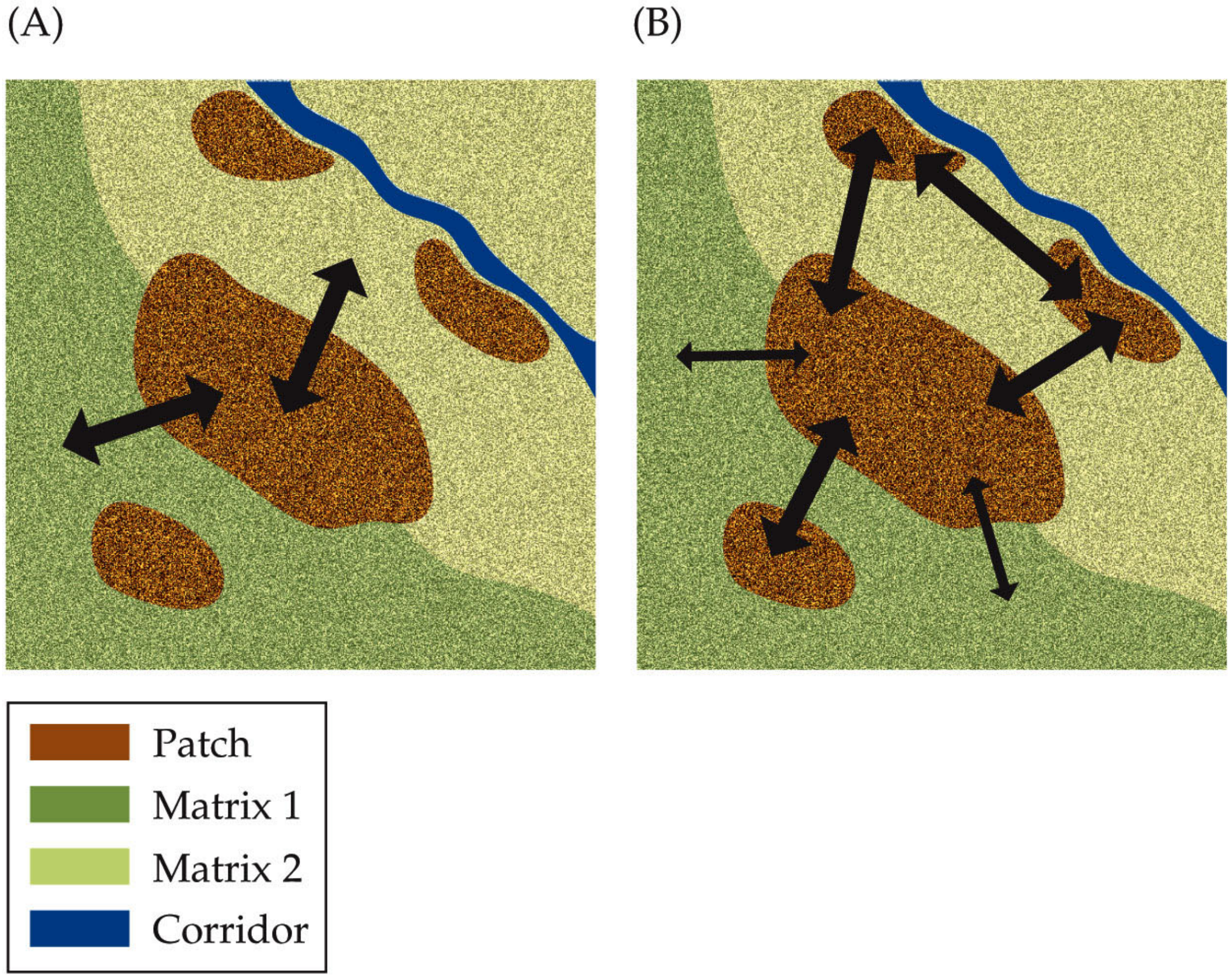
The ecosystems that make up a landscape are dynamic and interacting.

The interactions may occur through the flow of water, energy, nutrients, or pollutants between ecosystems.

There is also biotic flow as animals, seeds, pollen, and other biological emissaries move between them.

For biotic flow to occur, the patches must either be directly connected, or the surrounding habitat (the *matrix*) must be of a type through which dispersal is possible.

Figure 23.5 Interpatch Dynamics



ECOLOGY, Figure 23.5

Box 23.1 Thinking about Scale

Consideration of scale is very important in landscape ecology.

A landscape may be heterogeneous at a scale important to a tiger beetle, but homogeneous to a warbler or a moose.

The scale chosen for a study determines the outcomes.

Box 23.1 Thinking about Scale

Scale—the spatial or temporal dimension of an object or process, characterized by grain and extent.

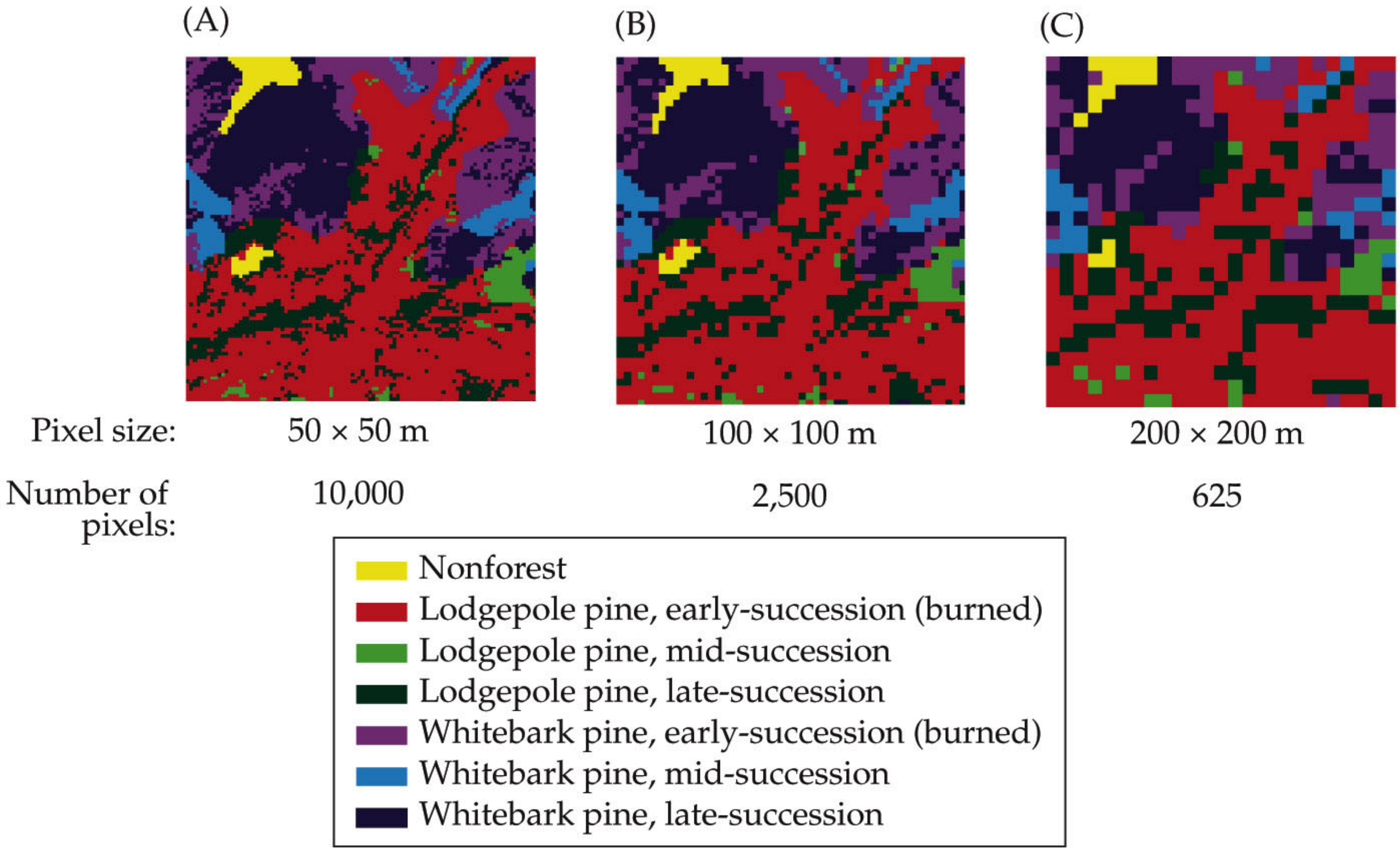
Grain—size of the smallest homogeneous unit of study (e.g., a pixel in a digital image); determines the resolution at which we view the landscape.

Extent—boundary of the area encompassed by the study.

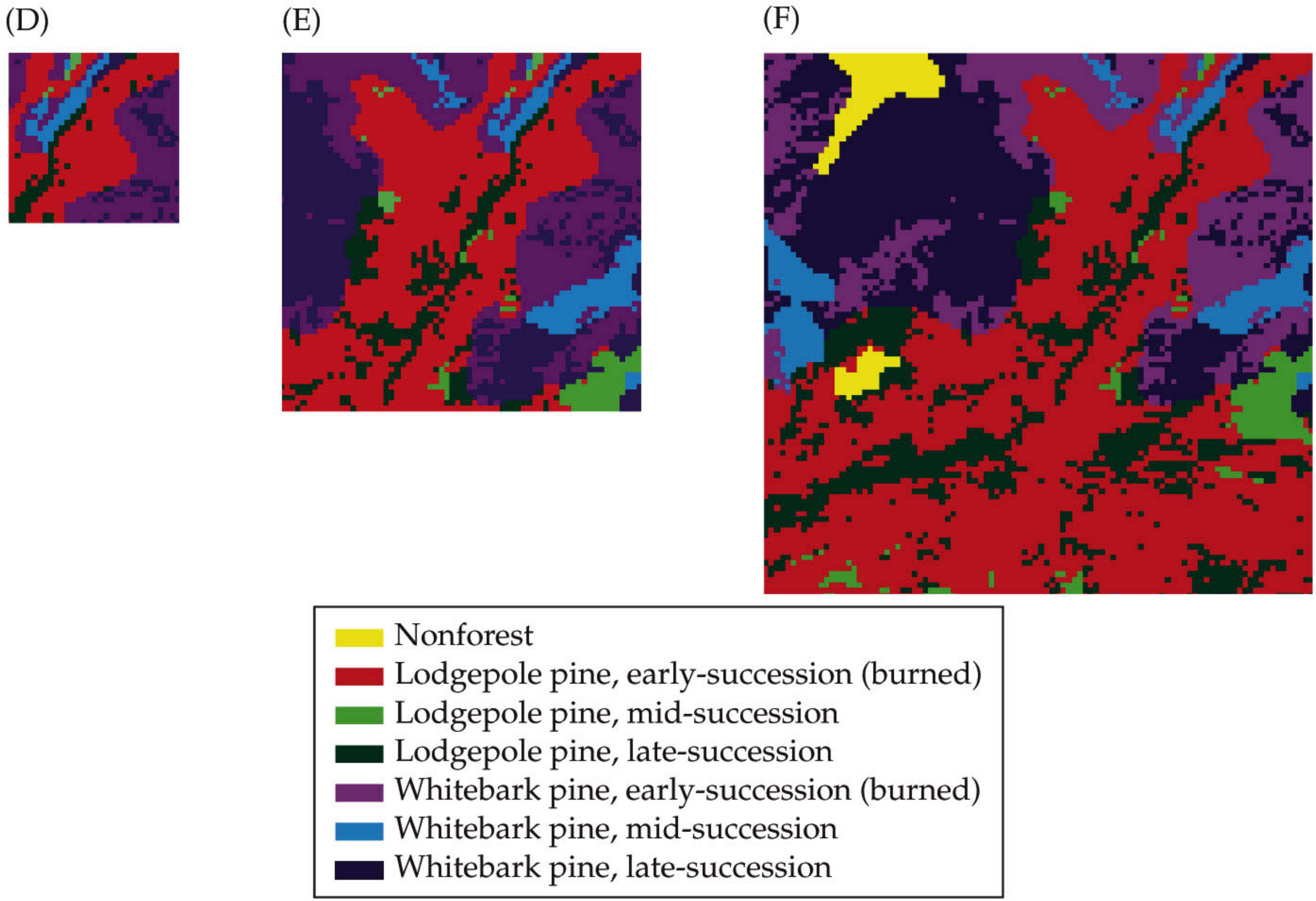
Box 23.1 Thinking about Scale

Grain affects the quantity of data that must be manipulated. A large-grained approach may be appropriate for regional to continental scales.

How the extent is defined can change the composition of the landscape being described.


(A)
(B)
(C)
Pixel size:
50 × 50 m
100 × 100 m
200 × 200 m
Number of pixels:
10,000
2,500
625
Nonforest
Lodgepole pine, early-succession (burned)
Lodgepole pine, mid-succession
Lodgepole pine, late-succession
Whitebark pine, early-succession (burned)
Whitebark pine, mid-succession
Whitebark pine, late-succession

Box 23.1, Figure A Effects of Grain and Extent (Part 2)



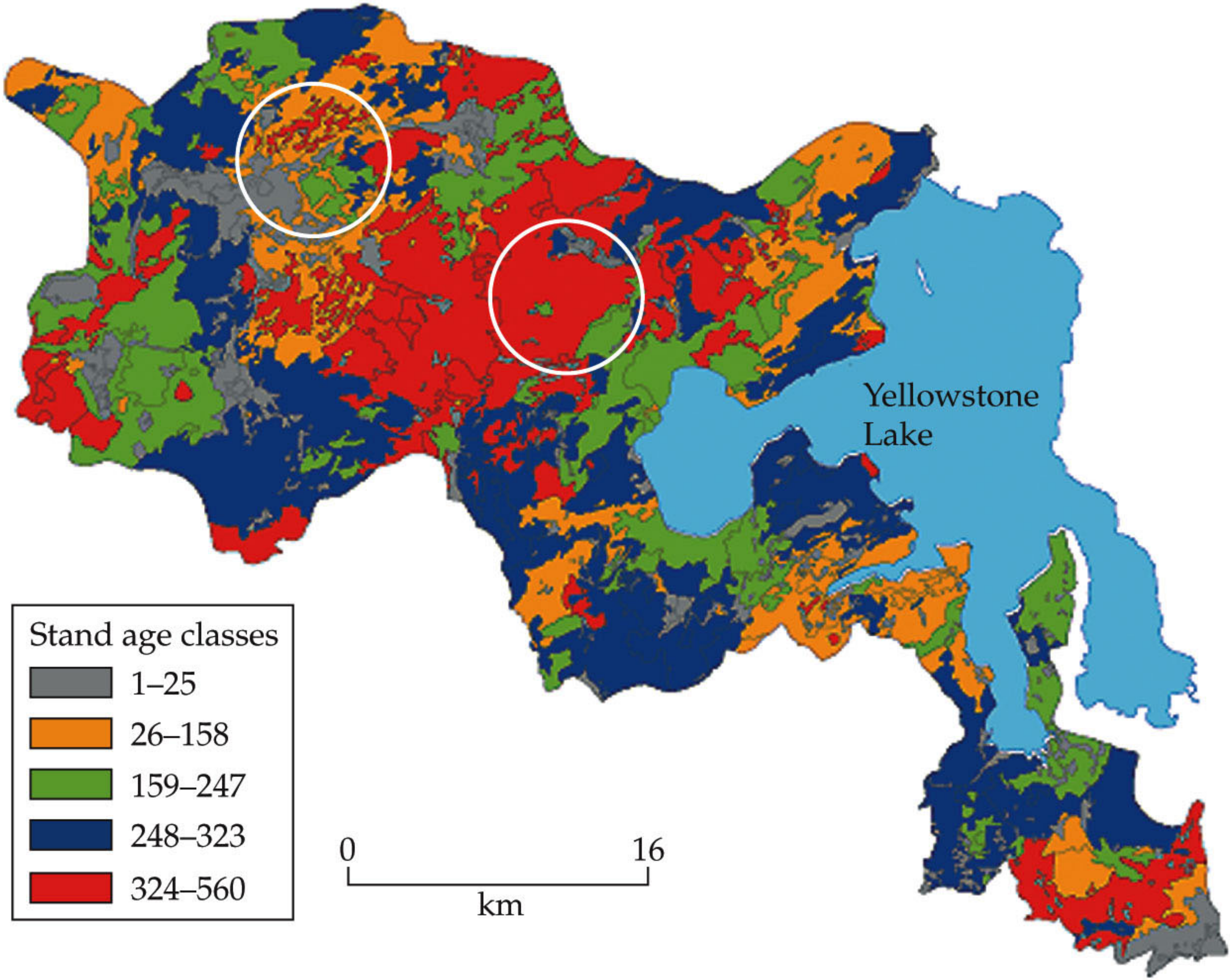
Landscape ecologists must also consider how processes scale up or down.

Example: How leaf-based measurements of CO_2 exchange scale up to the whole plant, the ecosystem, and ultimately to the mosaic of ecosystems that make up the landscape.

Landscape composition—kinds of elements or patches in a landscape, and amount of each kind present.

The elements are defined by the investigator and influenced by the source of the data used.

Figure 23.6 Landscape Composition and Structure



ECOLOGY, Figure 23.6

Example: Five age classes of lodgepole pine forest were determined by fieldwork, aerial photographs, and GIS.

Composition can be quantified by counting the kinds of elements in the mapped area (five), calculating the proportion of the mapped area covered by each element, or measuring the diversity and dominance of the different landscape elements.

Landscape structure—the physical configuration of the compositional elements.

Example: Some parts of the landscape are more fragmented than others.

Measures of landscape composition and structure address:

- Size of patches.
- If patches are aggregated or dispersed.
- Complexity of patch shape.
- Degree of fragmentation.

Landscape pattern can affect ecological processes in many ways.

It can affect whether and how animals move, and thus indirectly influence rates of pollination, dispersal, or predation.

In a study of a tropical bat in a fragmented habitat, Henry et al. (2007) found that connectivity determined bat density.

More isolated fragments were less likely to be visited by bats, even if they contained abundant food.

Landscape structure affected bat foraging behavior, and thus the dispersal patterns of the plants the bats fed on.

Landscape patterns also modulate biogeochemical cycling.

The interfaces between terrestrial and aquatic ecosystems are typically places of high rates of biogeochemical turnover.

Other factors can also play a role.

Example: Inputs of S, Ca, and N from atmospheric deposition were higher at forest edges than in forest interiors.

Denser canopies and greater physical complexity at forest edges resulted in greater interception of airborne particles.

Landscape patches vary in terms of habitat quality and resource availability.

Patch boundaries, connections between patches, and the matrix between patches can also affect population dynamics.

Example: Bog fritillary butterflies would cross readily from patch to patch when suitable patches were close together.

Where there was a wider distance of matrix to cross, the butterflies were more hesitant to leave a patch.

Shape and orientation of landscape patches is also important.

Gutzwiller and Anderson (1992) found that northward-migrating, cavity-nesting birds were more likely to nest in forest patches in the Wyoming grasslands that were oriented along an east–west axis.

The habitat patches serve as a net, intercepting birds as they migrate north.

The association was not seen for resident bird species.

In this case, landscape structure in part determines the species composition of the community.

Landscape patterns can in turn be caused by ecological processes.

Example: On Isle Royale in Lake Superior, moose grazing depresses primary productivity directly, and by altering rates of N mineralization and litter decomposition.

Moose browsing also shifts the composition of tree species toward spruce, and the predominance of spruce in turn feeds back to determine rates of biogeochemical processes.

Landscape patterns can impact disturbance rates, and ecosystems' vulnerability to disturbances.

In 1988, forest fires burned nearly one third of Yellowstone. A complex mosaic of patches resulted, that had burned at different intensities. This will probably dictate the composition of the landscape for decades, if not centuries.

Human activities also alter landscapes.

Agriculture, logging, and other disturbances continue to affect current biodiversity and ecosystem processes—even when people have left.

These are called *landscape legacies*.

The effects of anthropogenic disturbance can be detected even centuries after the disturbance.

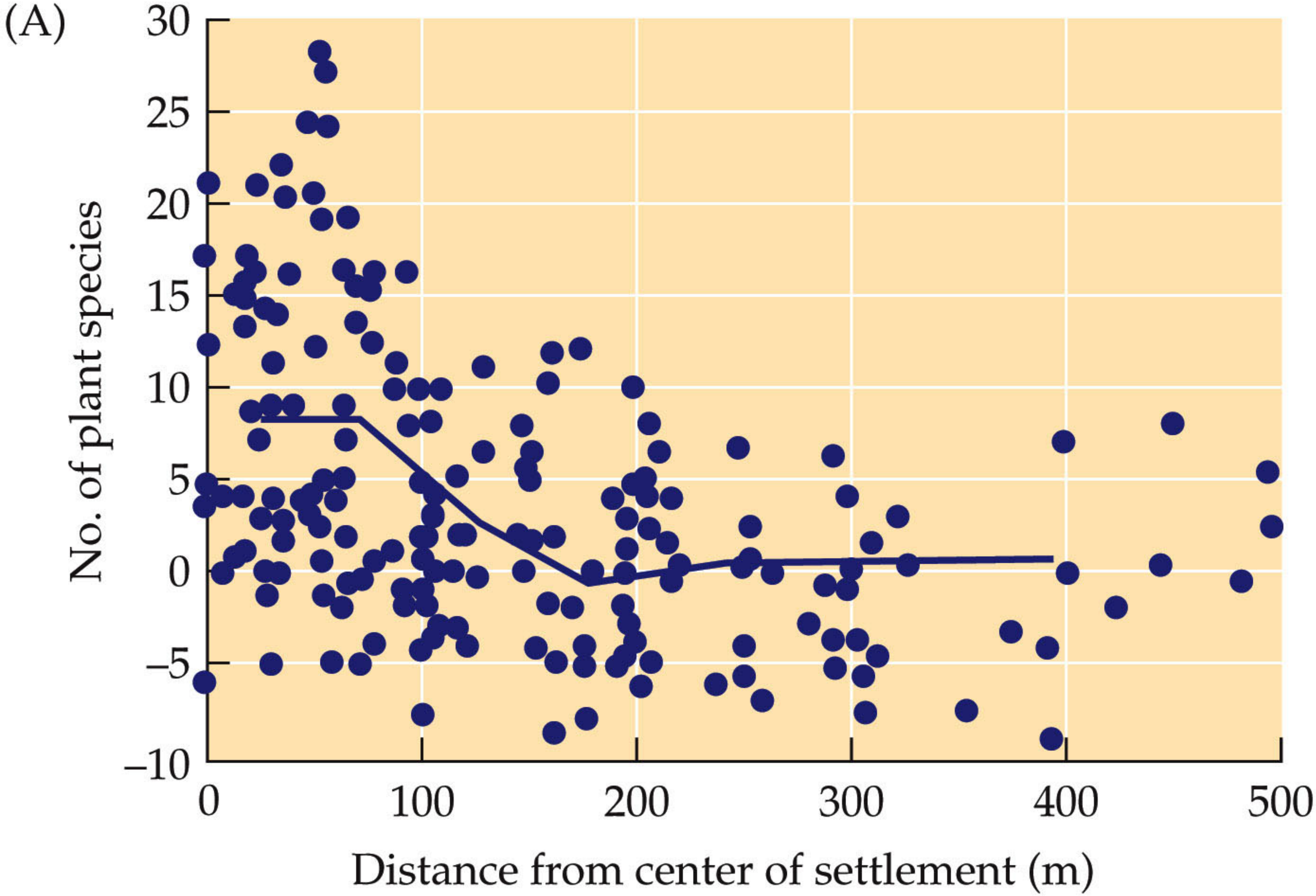
In central France, Dambrine et al. (2007) found that effects of Roman farming settlements were still evident after 1,600 years.

Plant species richness increased in the vicinity of Roman ruins, a consequence of higher soil pH.

This was thought to result from remnants of lime mortar used in Roman buildings and from agricultural practices.

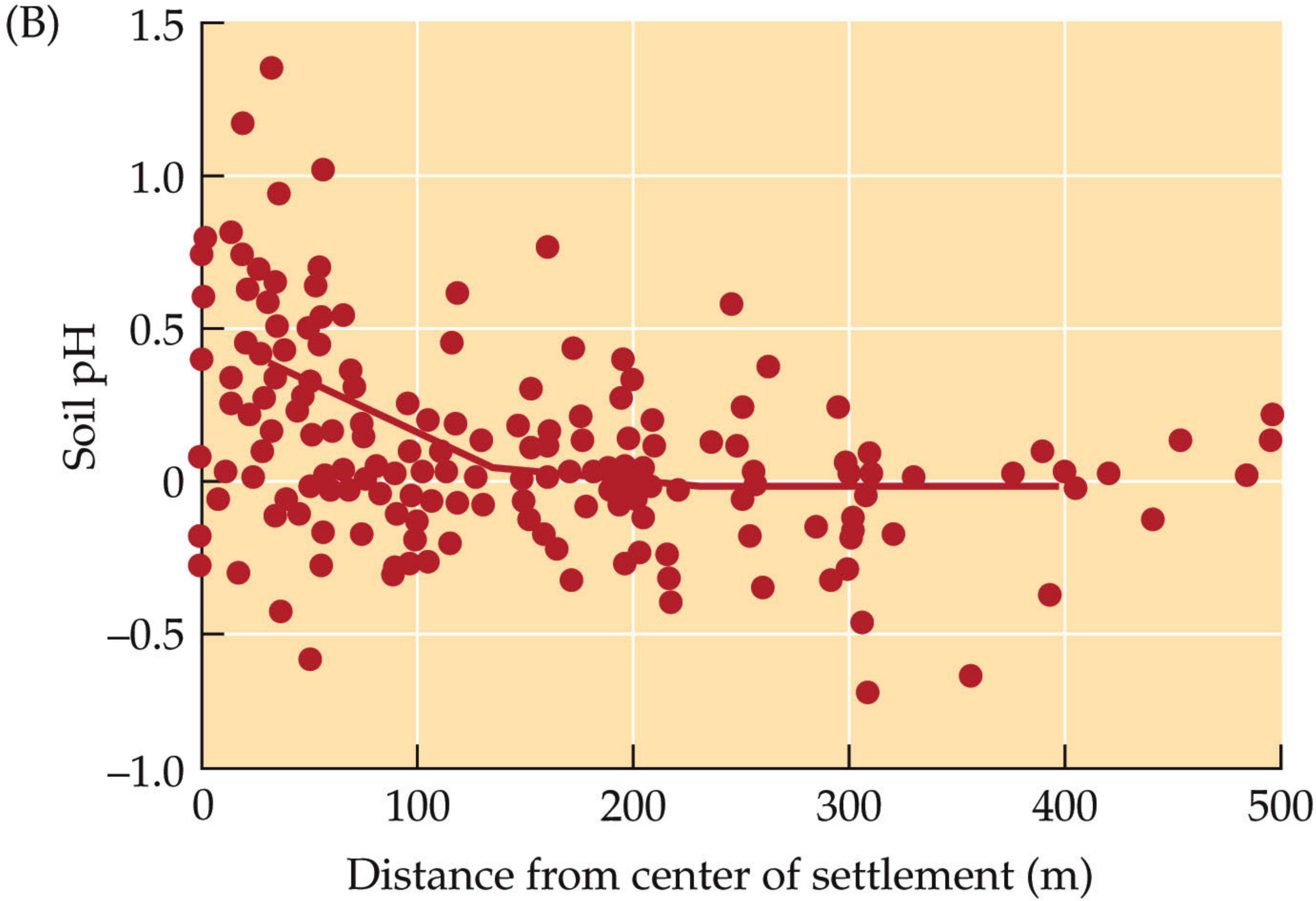
Soil phosphorus levels were also higher closer to the settlement sites.

Figure 23.9 Landscape Legacies (Part 1)



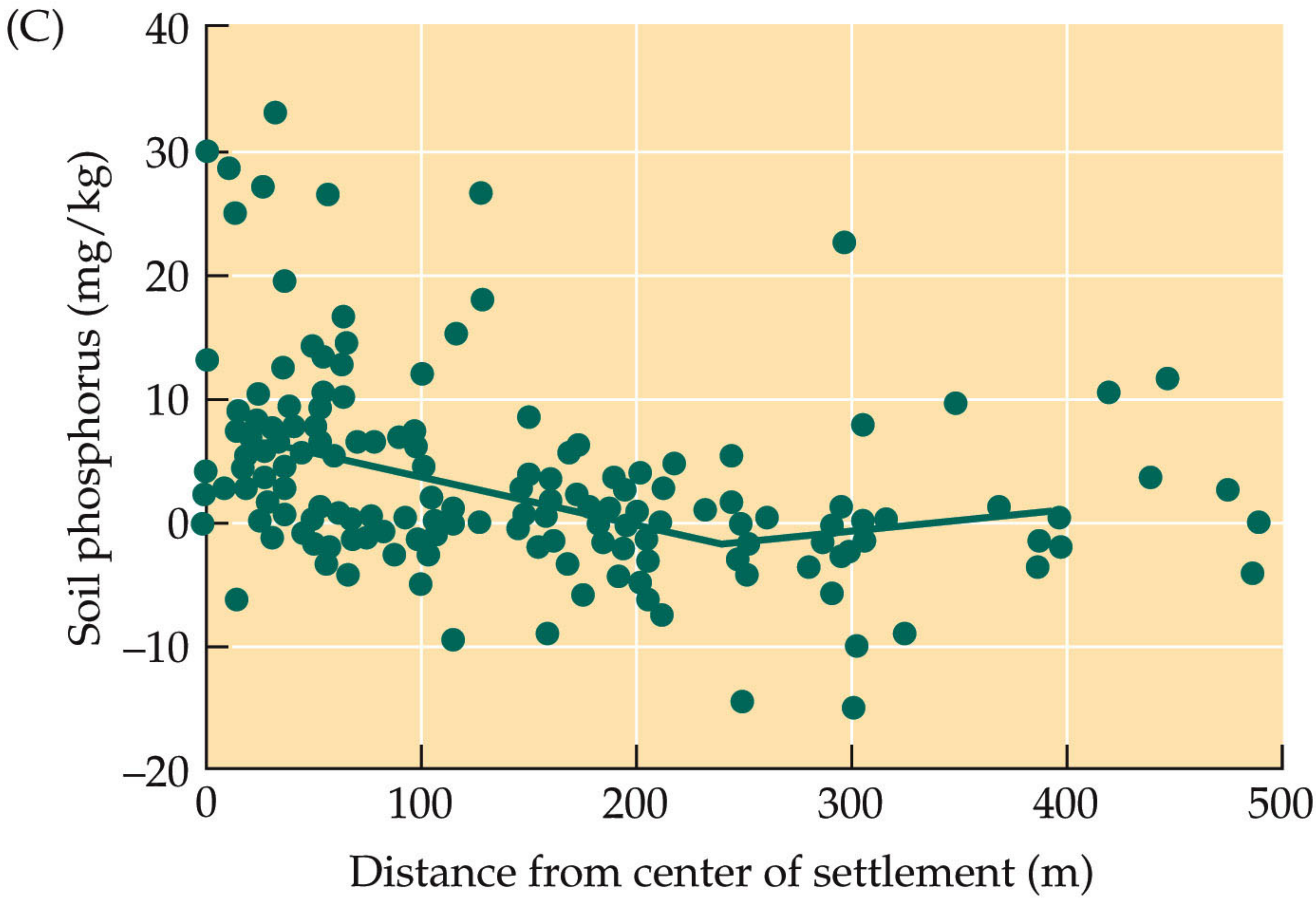
ECOLOGY, Figure 23.9 (Part 1)

Figure 23.9 Landscape Legacies (Part 2)



ECOLOGY, Figure 23.9 (Part 2)

Figure 23.9 Landscape Legacies (Part 3)




Study site
Rome
Roman Empire, C.E.117

Concept 23.2: Habitat fragmentation decreases habitat area, isolates populations, and alters conditions at habitat edges.

In 1986, a massive hydroelectric project in the Caroni River valley of Venezuela created islands of tropical forest surrounded by water in what had been an intact forest.

Figure 23.10 The Islands of Lago Guri

ECOLOGY, Figure 23.10

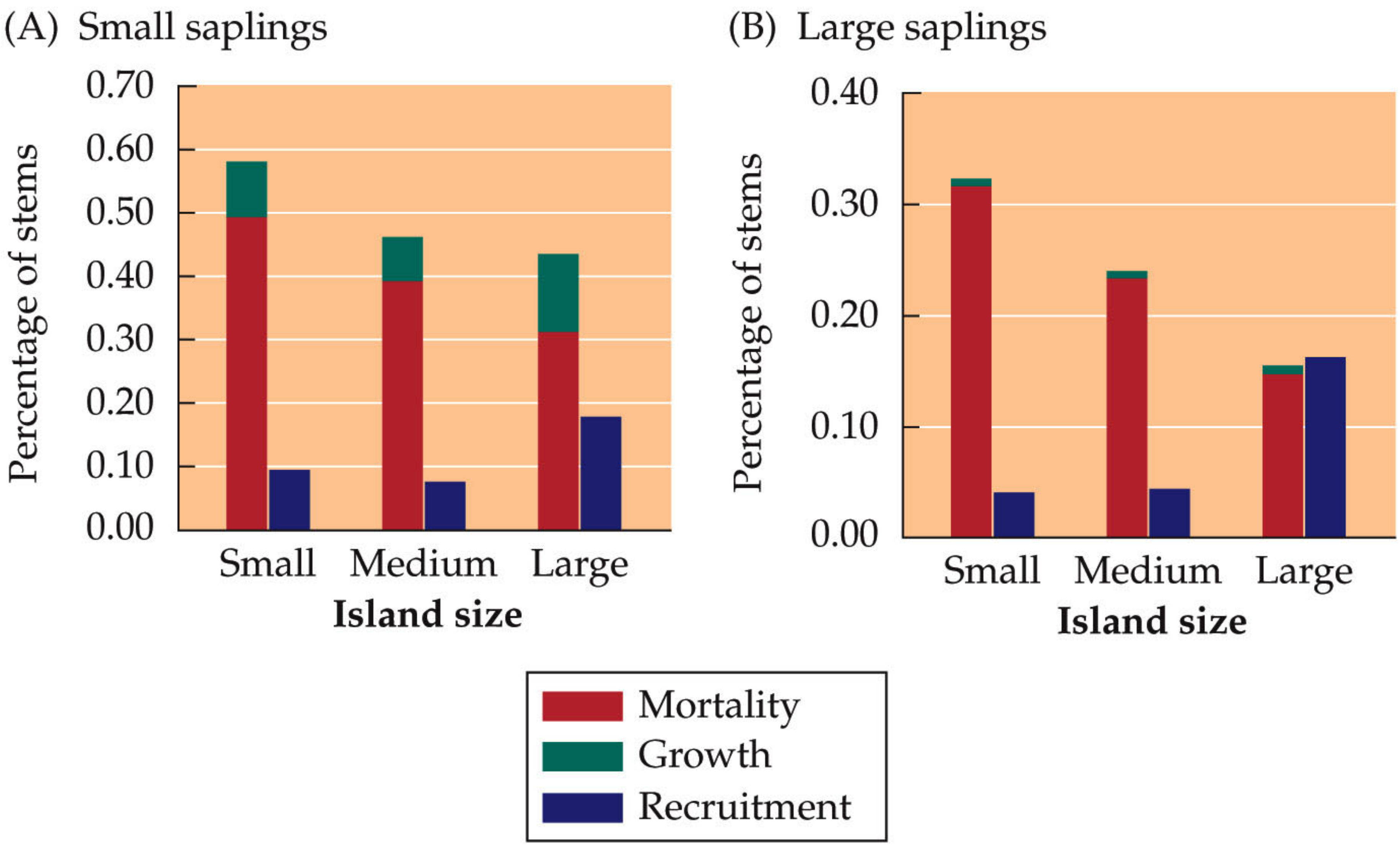
Habitat Fragmentation

This landscape change was studied by Terborgh et al. (2006).

Small and medium-sized islands were lacking the top predators found on the mainland—cats, raptors, large snakes.

Generalist herbivores, seed predators, and predators of invertebrates were 10 to 100 times more abundant on the islands.

Figure 23.11 Effects of Habitat Fragmentation by Lago Guri



Habitat Fragmentation

This had a dramatic effect on the vegetation: Tree recruitment decreased and tree mortality increased due to high rates of herbivory, primarily by leaf-cutter ants.

This was seen as an example of top-down regulation.

Habitat Fragmentation

Human activities convert large blocks of landscape—flooding, clearing, urbanization, roads, etc.

Consequences include:

- Reduction of habitat available for other species. This contributes to the declines of thousands of species.

Habitat Fragmentation

- Fragmentation results in increasing edge effects.
- Fragmentation results in spatial isolation of populations, making them vulnerable to the problems of small populations.

Habitat Fragmentation

The process of habitat fragmentation may take many decades.

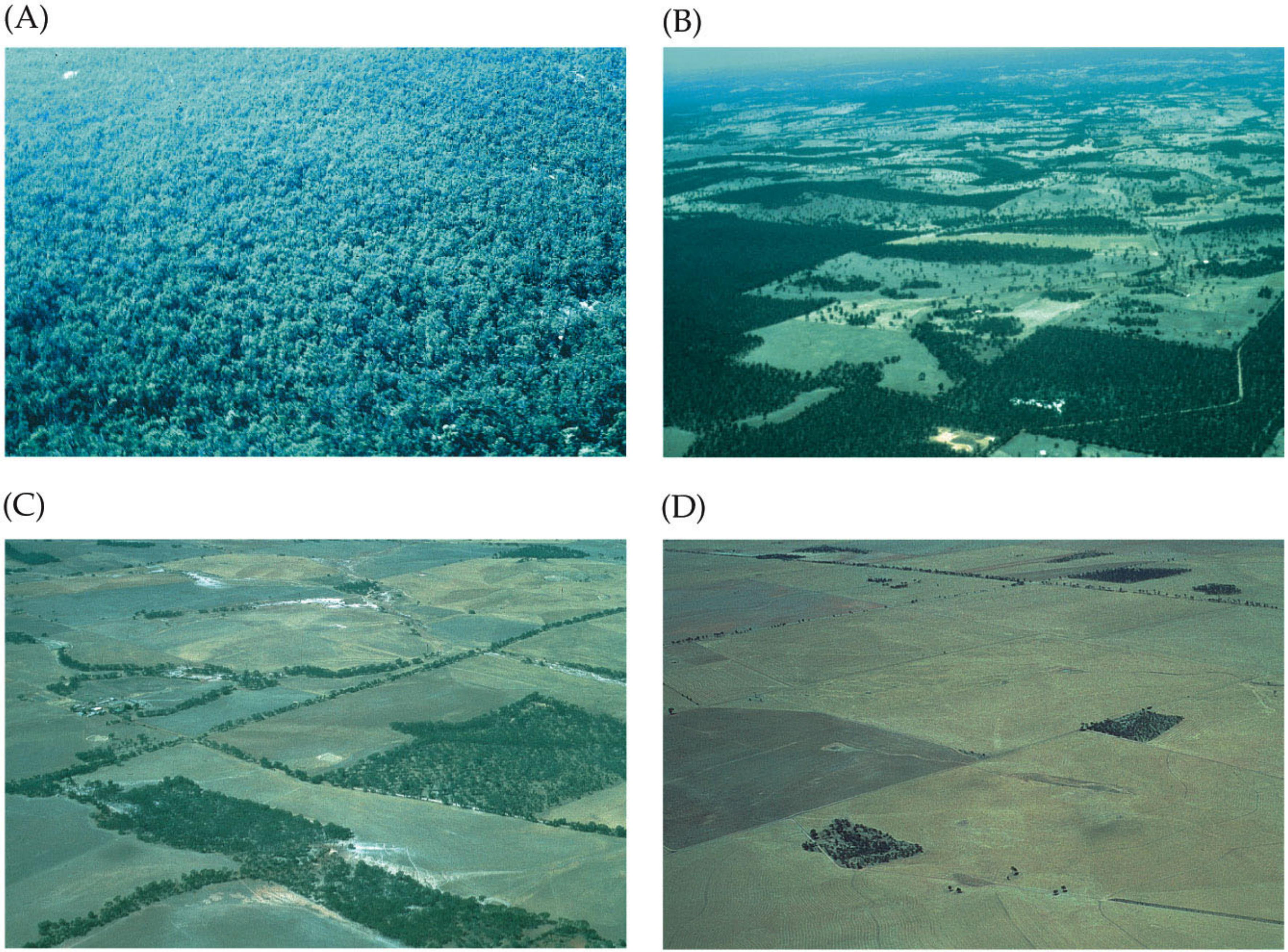
Roads are often catalysts of habitat conversion.

Fragmentation is a reversible process. The forests of the northeastern U.S. are much more extensive than they were a century ago.

Habitat Fragmentation

The global trend, however, is toward net loss of forests and increasingly fragmented forest and other ecosystems.

Figure 23.12 The Process of Habitat Fragmentation



ECOLOGY, **Figure 23.12**

Habitat Fragmentation

When habitat is fragmented, some species go extinct within many of the fragments.

There may be inadequate resources, disruption of mutualisms, and top-down effects.

Some species flourish under the changed conditions.

Habitat Fragmentation

Fragmentation often leads to loss of top predators, giving rise to cascading effects.

Example: In the Hudson River valley, forest fragments of less than 2 hectares contained very high populations of white-footed mice—there are no predators, and few competitors.

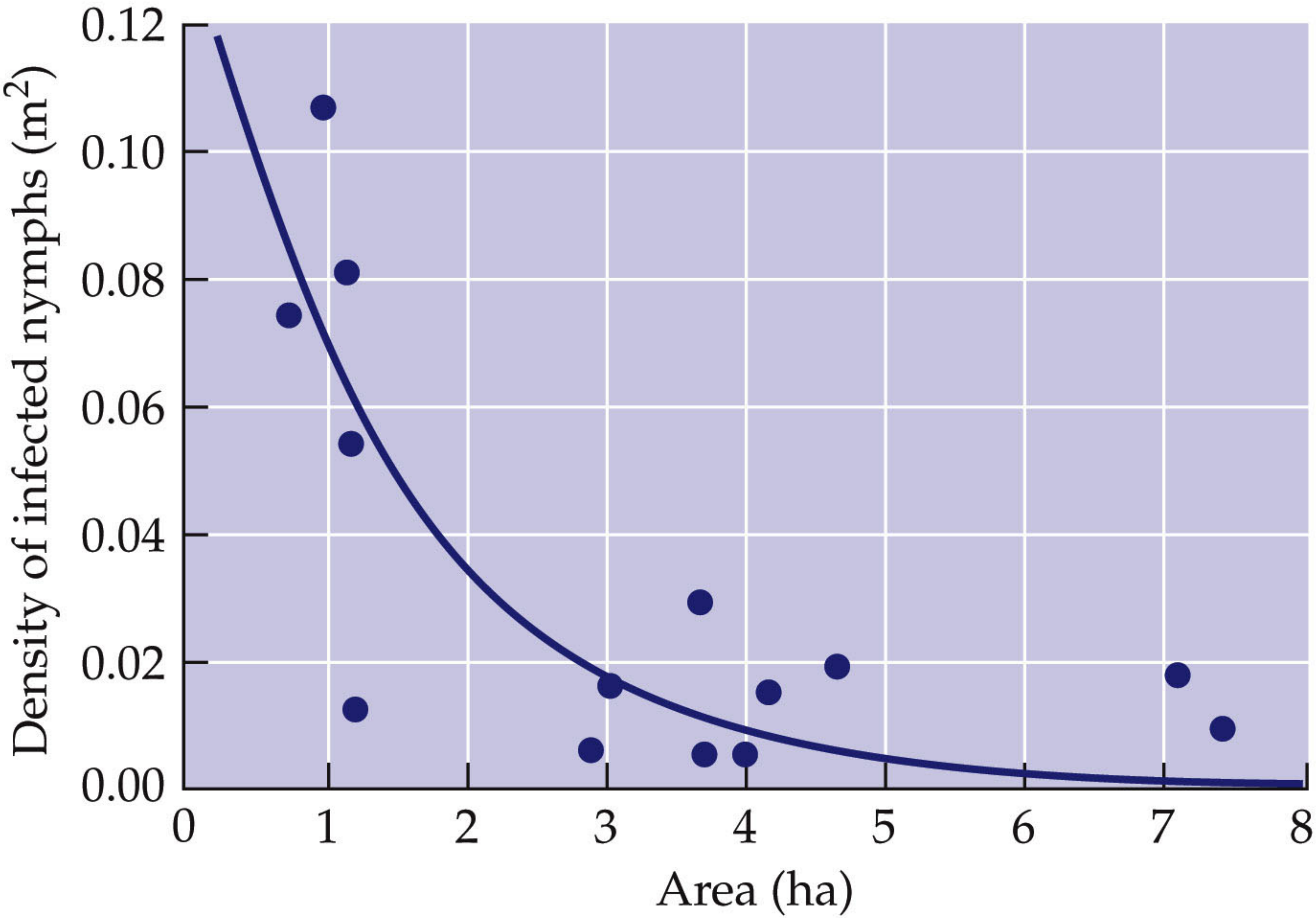
Habitat Fragmentation

White-footed mice are the most important reservoir of the bacterium that causes Lyme disease. Ticks are the vector.

Ticks collected in small forest fragments are much more likely to carry the bacterium than in large fragments.

The outcome is increased risk of human disease, ultimately a result of habitat fragmentation.

Figure 23.13 Habitat Fragmentation Can Have Consequences for Human Health



ECOLOGY, Figure 23.13

Models for fragmented landscapes were initially derived from island biogeography theory.

A study in Western Australia used radiotelemetry to study movements of the eastern wallaroo.

Habitat fragments existed in a matrix of wheat fields.

(A)

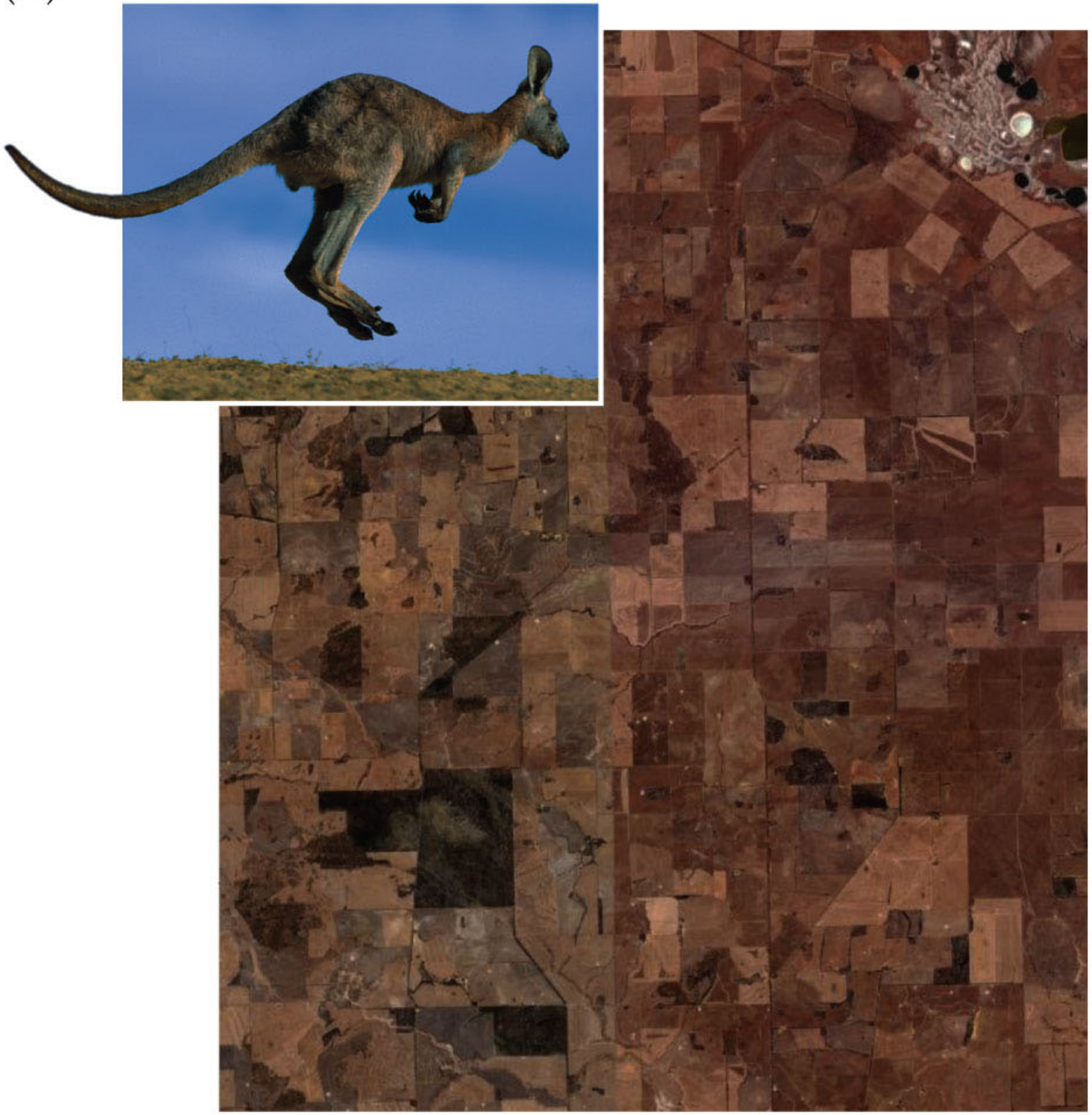
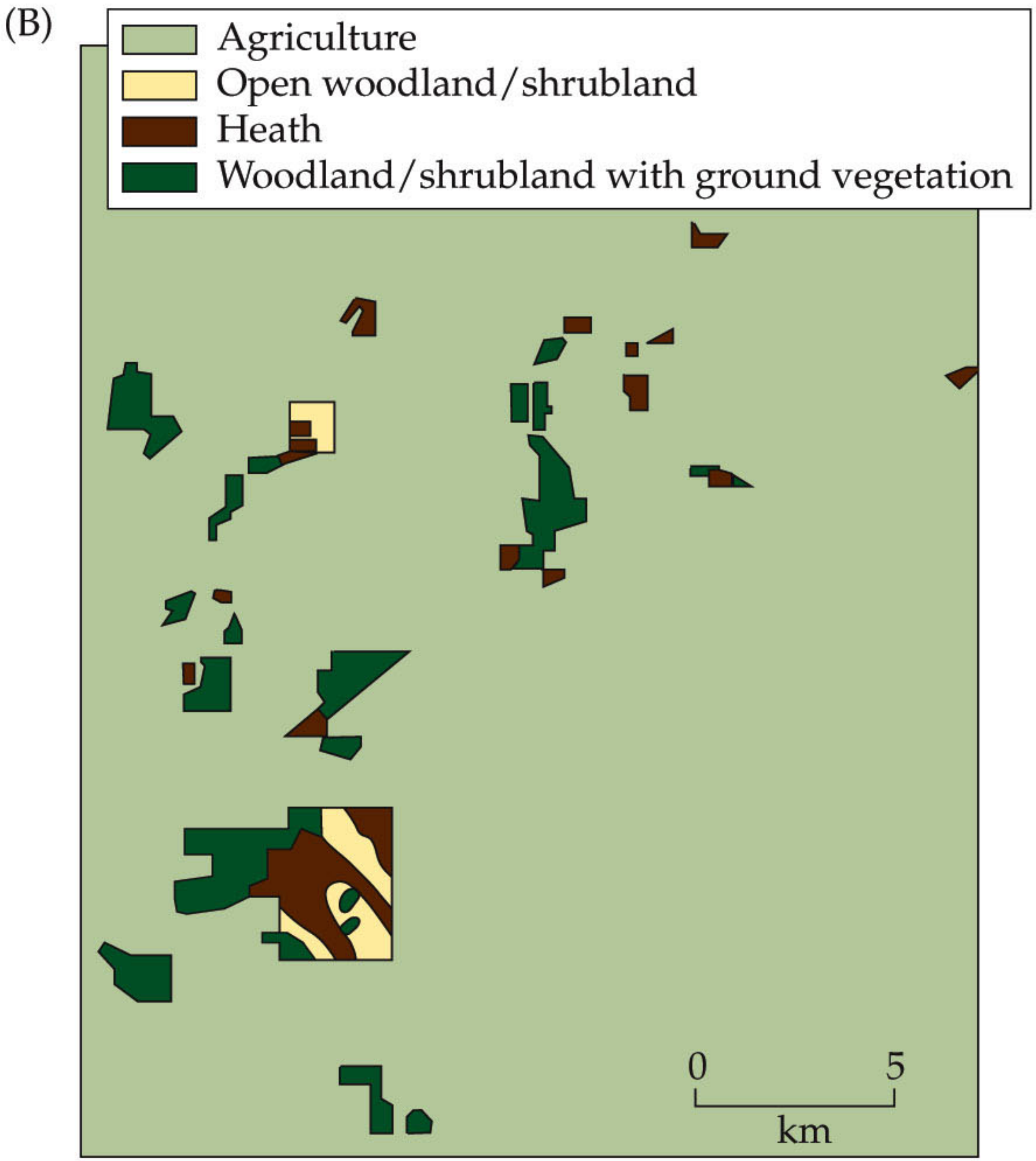


Figure 23.14 Habitat Islands (Part 2)



Habitat Fragmentation

Walleroos living in large fragments tended to stay there.

They would move freely between small fragments if they were clustered.

These habitat fragments were functioning more or less as islands surrounded by a matrix.

Fragmented landscapes are more complex than island models would suggest, at least for some species.

The matrix may be *permeable* to some extent, and may form a mosaic of different patch types, of which some are more permeable than others.

Habitat Fragmentation

Example: In one study in South America, small birds were translocated to habitat fragments in different landscape contexts.

Birds translocated to fragments surrounded by pasture were much more reluctant to leave to move to larger forested blocks (matrix not permeable).

Habitat Fragmentation

Birds that had a shrubby habitat to cross or were in fragments connected to larger forest blocks by a forested corridor would move more often (matrix permeable).

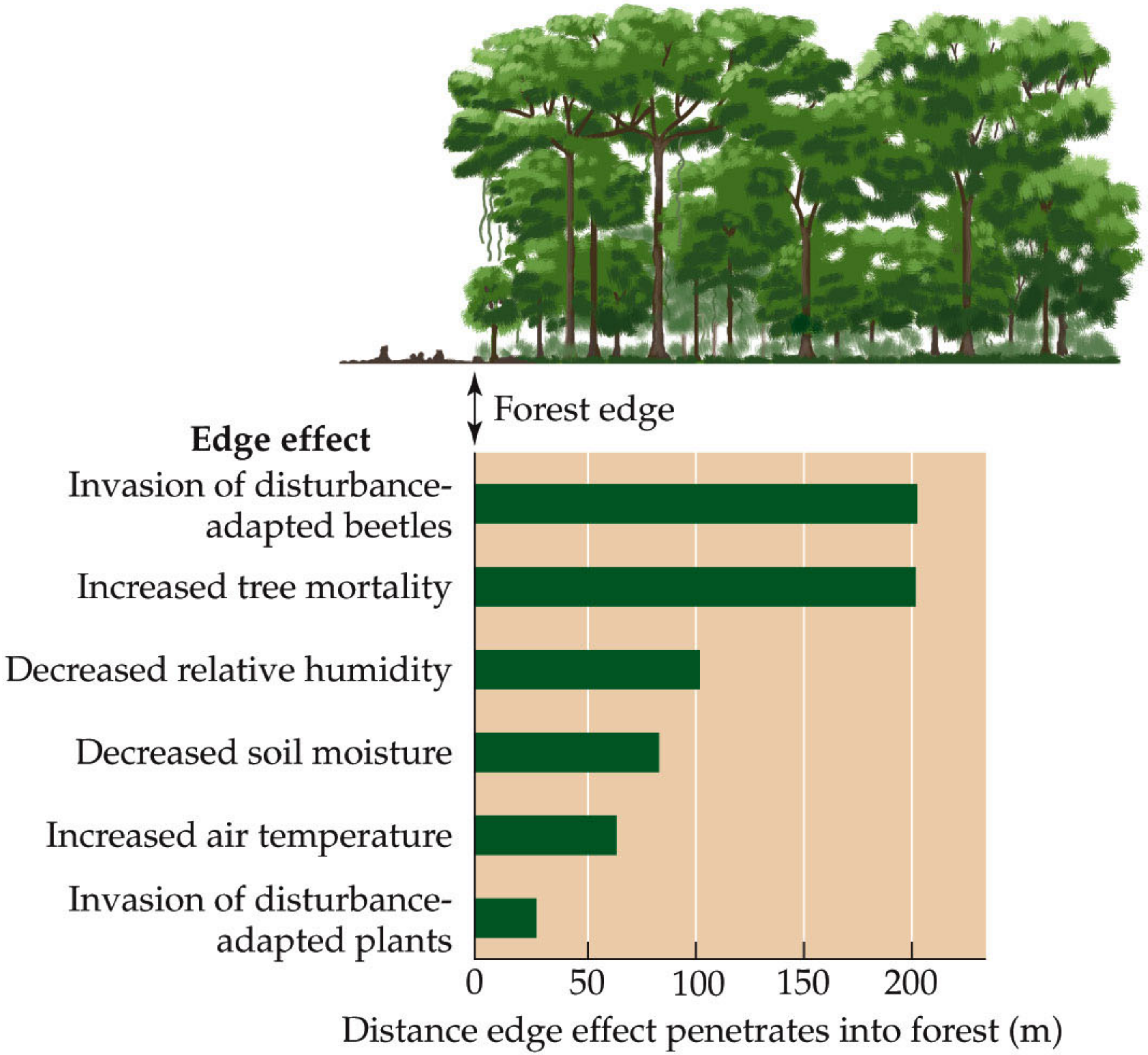
Studies with rodents showed that some species would cross a particular matrix, while others would not.

Boundaries, or *edges*, increase as fragmentation increases.

Edge effects—biotic and abiotic changes that are associated with such a boundary.

The physical environment changes over a certain distance into the remaining fragment, and thus biological interactions and ecological processes can change as well.

Figure 23.15 Edge Effects



***ECOLOGY*, Figure 23.15**

Chen et al. (1995) studied edge effects in old-growth Douglas fir forest in the Pacific Northwest.

Abiotic edge effects included higher temperatures and diurnal extremes, higher wind speeds, and more light penetration.

There was variation in how far in the effects extended, and they were more pronounced on south-facing edges.

Habitat Fragmentation

The biotic consequences of the abiotic edge effects included higher rates of decomposition, more wind-thrown trees and more woody debris, and differential seedling survival.

Pacific fir seedlings survived better than Douglas fir and western hemlock.

Habitat Fragmentation

Habitat edges can promote or deter dispersal.

Some species may benefit from foraging in one habitat and reproducing in another.

Invasive species are commonly more abundant in habitat edges.

Novel species interactions may take place at the junctions of two ecosystems.

Johnson and Temple (1990) studied five species of ground-nesting birds in the tallgrass prairie.

Proximity to a wooded edge significantly increased the probability of nest predation and nest parasitism by cowbirds, significantly lowering reproductive success.

Habitat Fragmentation

Habitat edges also pose increased risk from human activities.

Species that are vulnerable to hunting, selective logging, or other harvesting decline following creation of an edge.

Domesticated animals may wander into habitat fragments, causing degradation or predation on wild species.

Habitat Fragmentation

Habitat fragmentation can also influence evolution, which we have only begun to understand.

A study of bumblebee behavior in fragmented plots of different sizes showed that bees visited flowers of wood betony less frequently in the fragments than in control plots. Once in fragments, they tended to stay there.

Habitat Fragmentation

These changes in bumblebee behavior resulted in lower probability of pollination, and increased likelihood of inbreeding for the wood betony in the fragments.

This could cause an altered evolutionary trajectory for those plants (Goverde et al. 2002).

Habitat fragmentation tends to increase rates of inbreeding and genetic drift and alters selection regimes for those species confined to fragments.

Populations of a flightless ground beetle that had been isolated by roads showed significant genetic variation (Keller and Largiadèr 2003).

Habitat Fragmentation

When plant populations become small and isolated, their chances of encountering pollinators, pathogens, herbivores, dispersers, and competitors may decrease, with subsequent evolutionary consequences.

Animal breeding systems may change as well.

Cottontail rabbits in small habitat fragments in New Hampshire had male-skewed sex ratios and higher mortality rates than rabbits in large habitat blocks (Barbour and Litvaitis 1993).

Both factors could influence selection on these populations.

Designing Nature Reserves

Concept 23.3: Biodiversity can best be sustained by large reserves connected across the landscape and buffered from areas of intense human use.

Principles of landscape ecology and conservation biology guide biologists in selecting the most vital lands for conservation.

Core natural areas—conservation of biodiversity and ecological integrity takes precedence over other values or uses, and “where nature can operate in its own way in its own time” (Noss et al. 1999).

Populations in core areas may serve as sources of individuals for populations outside the protected area.

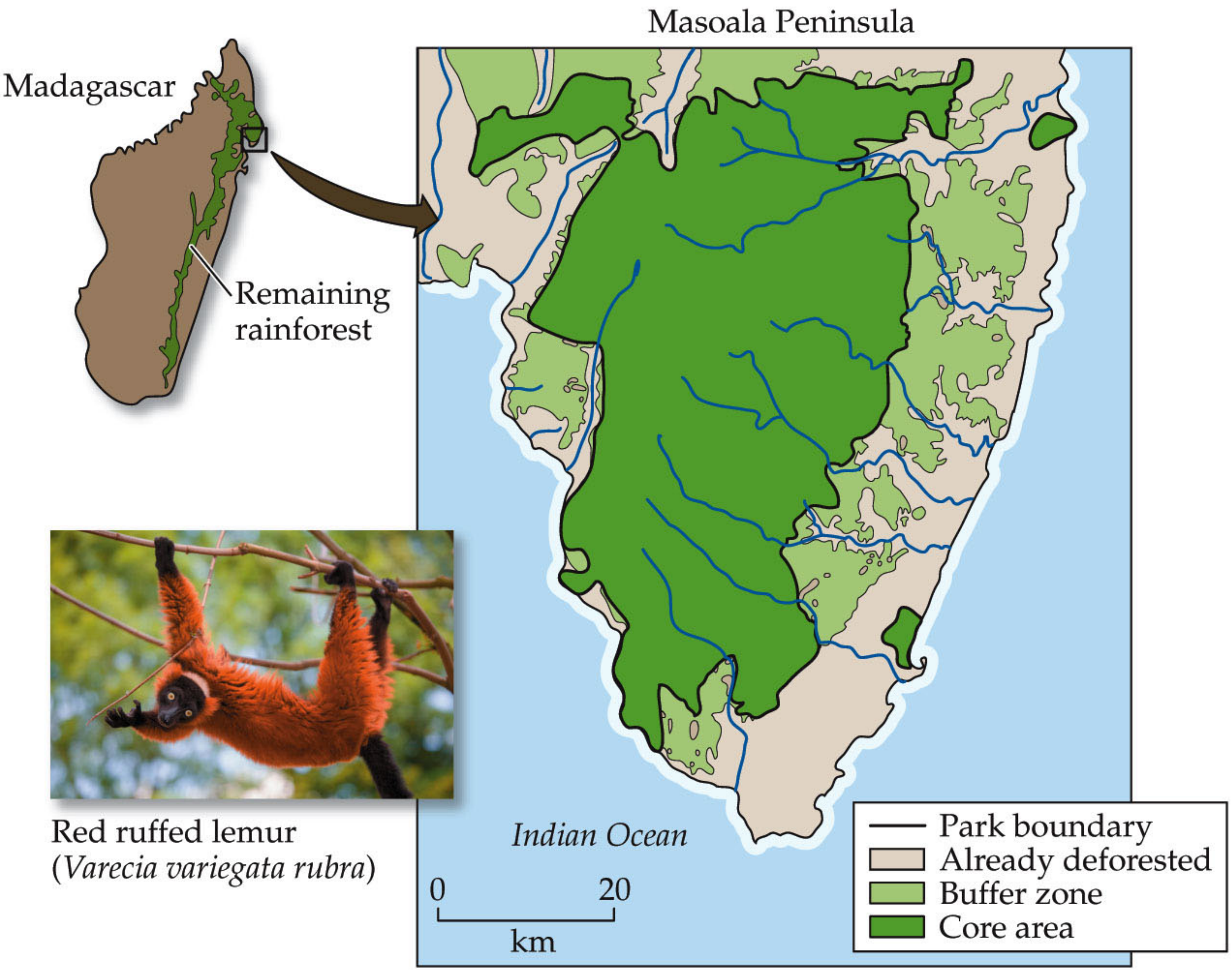
Ideally, core areas provide enough land to meet large habitat area requirements of top predators.

Designing Nature Reserves

Design of Masoala National Park in Madagascar involved careful planning that took both ecological and socioeconomic concerns into account.

The core area extends across several elevation and precipitation zones, encompassing a range of vegetation types.

Figure 23.16 Designing Masoala National Park



Red ruffed lemur
(*Varecia variegata rubra*)

ECOLOGY, Figure 23.16

Designing Nature Reserves

The core area has not been affected by deforestation, and includes habitat for all the region’s rare species.

Areas close to villages that had already been fragmented and where hunting had negatively affected animal populations were avoided (Kremen et al. 1999).

Designing Nature Reserves

Ideally, core natural areas must be large and uncut by roads, or even by trails.

Not all protected areas qualify, and do not fully serve the purpose of protecting the whole biota from human interference.

U.S. national parks were not designed to protect biodiversity. Many were designed to protect scenery.

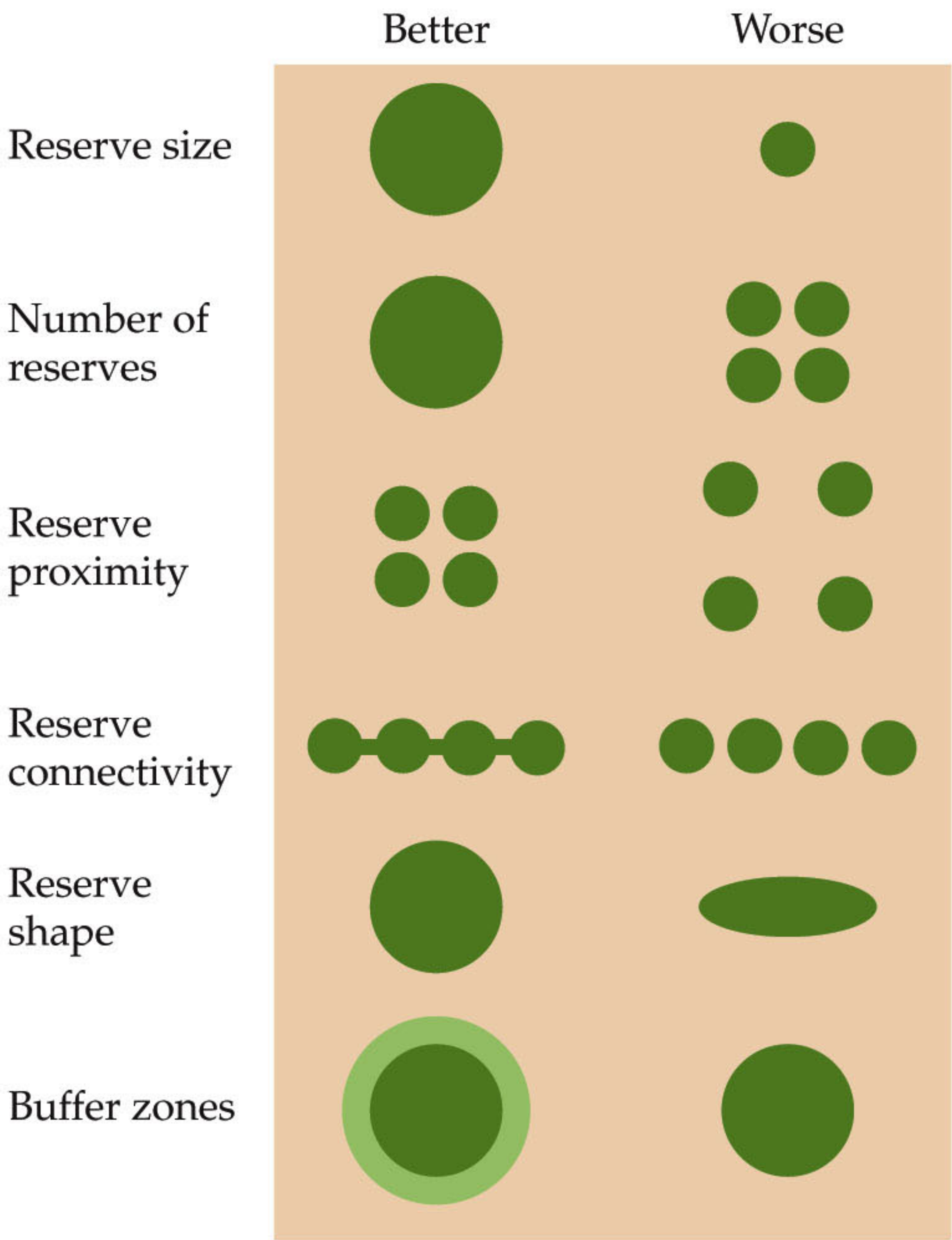
Designing Nature Reserves

Some spatial designs are better than others for fostering biodiversity.

Large, compact, and connected reserves are ideal.

But smaller or disconnected reserves may sometimes be more desirable (e.g., diseases would spread less quickly).

Figure 23.17 The Best Spatial Configurations for a Core Natural Area



Designing Nature Reserves

The primary objectives of reserve configuration are:

- Maintenance of the largest possible populations.
- Habitat for species throughout their area of distribution.
- Adequate area for maintenance of natural disturbance regimes.

Biological reserves—smaller reserves with conservation of a single species or ecological community as the main objective.

Although small, they can be important, especially where human population density is high and large reserves are not feasible.

Core areas can be augmented by **buffer zones**—large areas with less stringent controls on land use, but can still meet the requirements of many species.

Buffer zones can also be managed for harvest of resources such as timber, fiber, wild fruits, nuts, and medicines.

Grazing, logging, agriculture, and limited housing may also be possible.

Designing Nature Reserves

Masoala National Park design includes 71,000 hectares of forest land designated for sustainable timber harvesting.

Buffer areas were determined by proximity to villages, how much wood was needed to sustain them, and how much land was needed to provide this.

Designing Nature Reserves

Buffer zones can also become *population sinks* for some species, as animals that stray from core areas to buffer zones become vulnerable to hunting, roadkill, or other sources of mortality.

Designing Nature Reserves

Habitat corridors—linear patches that connect blocks of habitat.

Connectivity can reduce the effects of fragmentation by preventing isolation of populations.

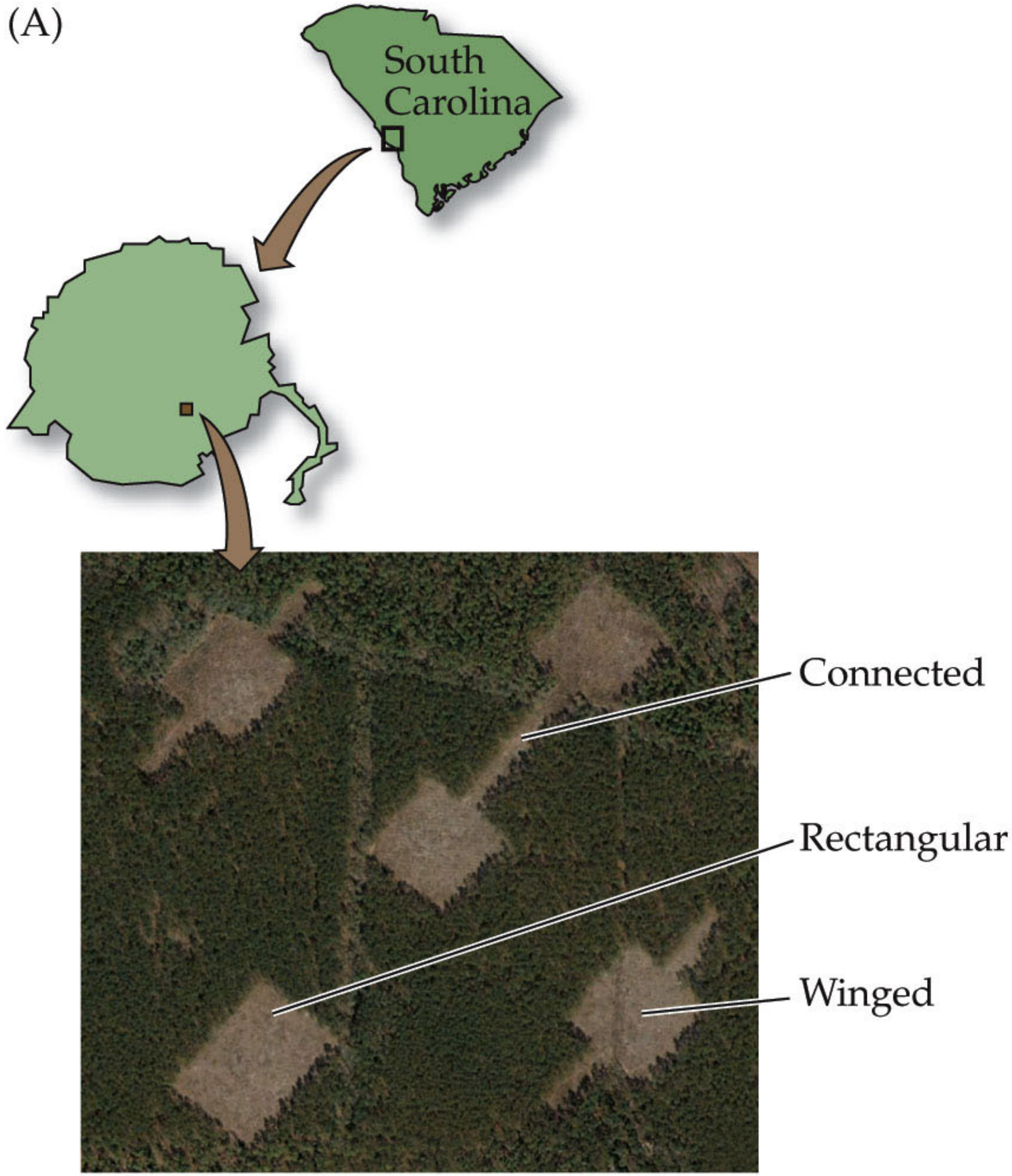
Do they work?

A test of habitat corridors was made at the Savannah River Ecological Laboratory, SC.

Patches of early successional habitat were established in a matrix of pine forest, some connected by corridors.

Corridors did facilitate movement of butterflies, pollen, and bird-dispersed fruits.

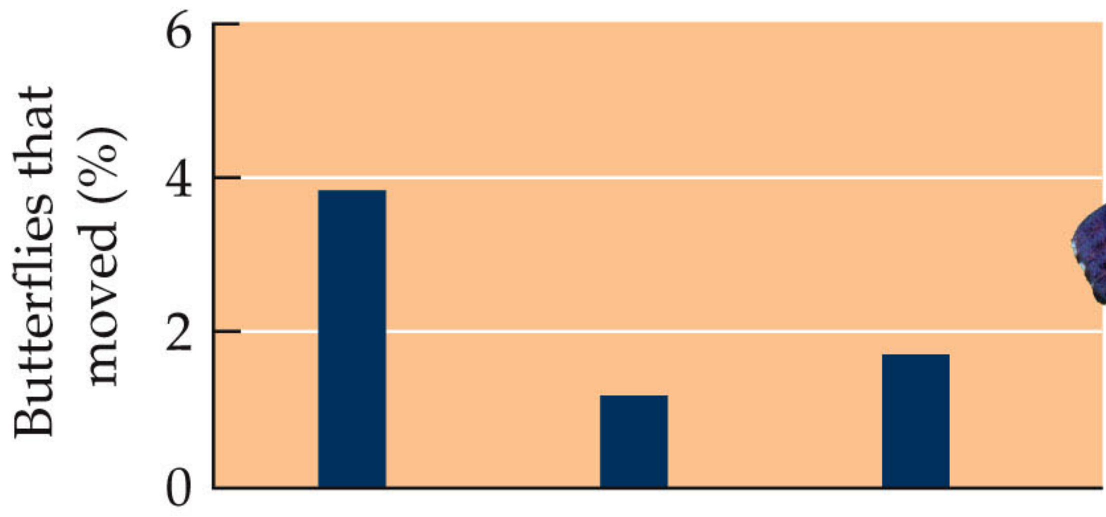
Figure 23.18 How Effective Are Habitat Corridors? (Part 1)



ECOLOGY, Figure 23.18 (Part 1)

Figure 23.18 How Effective Are Habitat Corridors? (Part 2)

(B)



(C)

***ECOLOGY,* Figure 23.18 (Part 2)**

But other studies of corridors have found negative effects, or no benefits.

At the Savannah River experiment, indigo bunting nest predation was higher in patches connected by corridors.

Corridors may also facilitate movement of pathogens and invasive species.

Santa Rosa National Park, Costa Rica, in a lowland tropical dry forest, was separated from upland forest habitat of nearby mountains by 35 km of cattle pasture and forest fragments.

David Janzen knew the importance of elevational migration for many tropical insects, birds, and mammals, and also saw the dry tropical forest disappearing.

He initiated the largest ecological restoration project of the Neotropics.

The Area de Conservación Guanacaste (ACG) includes protected areas (including 3 national parks), a protected corridor linking them, and the surrounding agricultural areas.

The region is home to some 230,000 species, or 65% of the species in Costa Rica.

Cattle ranches are being converted back to native vegetation by planting trees, suppressing fires, and limiting hunting.

Fire suppression and some grazing will help control an invasive grass, Jaragua grass.

Ultimately, the plan for the ACG calls for the restoration of about 75,000 hectares.

Restoration ecology attempts to recreate ecosystems that function properly, based on ecological knowledge.

A successful restoration requires:

- Correct diagnosis of the ecological state of the area.
- Determining the goals of the restoration.
- Application of ecological knowledge to recreate the desired type of ecosystem.

The process at Guanacaste is working, but it is a very long and slow one.

Janzen tries to restore not only the landscape, but also the people’s relationship with the land and the organisms.

This reflects a profound shift in how we relate to and manage land.

Concept 23.4: Ecosystem management is a collaborative process with the maintenance of long-term ecological integrity as its core value.

Through most of the 20^{th} century, management of public lands focused on resources of economic interest.

This focus remained at the core of land management policies until the 1980s.

The controversy over spotted owls versus logging of old-growth forests was a legacy of this management strategy.

There was huge opposition to listing the spotted owl as endangered, because people saw it as a threat to their livelihood. The ESA provides for protection of habitat for endangered species.

Ecosystem Management

Gradually, natural resource agencies expanded their missions to include "multiple use," in recognition that it was possible to manage public lands to meet diverse and at times competing demands.

It was often done by dividing land into different areas for different uses.

Ecosystem Management

The goals of land management have now shifted with the necessity of preserving biodiversity.

Ecosystem management has emerged as a way to include protection of all native species and ecosystems and to focus on the sustainability of the whole ecosystem.

Ecosystem Management

Ecosystem management attempts to maintain the sustainability of ecosystems, in part by setting goals and using science to evaluate and adjust management practices over time.

TABLE 23.1

Differences between Traditional Natural Resource Management and Ecosystem Management

Traditional management	Ecosystem management
Emphasis on commodities and natural resource extraction	Emphasis on balance between commodities, amenities, and ecological integrity
Equilibrium perspective; stability; climax communities	Nonequilibrium perspective; dynamics and resiliency; shifting mosaics
Reductionism; site-specific	Holism; view of lands in landscape context
Predictability and control	Uncertainty and flexibility
Solutions developed by resource management agencies	Solutions developed through discussions among all stakeholders
Confrontation; single-issue polarization; public as adversary	Consensus building; multiple issues; partnerships

Source: Meffe et al. 2002.

Ecosystem Management

Since the old-growth forest debates in the 1980s, more collaborative decision making has been combined with better use of science to arrive at management plans that are responsive to people’s livelihoods.

Ecosystem Management

Ecosystem management focuses on biophysical ecosystems, or *ecoregions*, delineated by natural boundaries rather than political boundaries (e.g., a watershed).

The full range of people with some interest in the project (*stakeholders*) are involved in decision making for the ecoregion.

Most projects begin with gathering and evaluating scientific data to define the nature of the problems, and to set sustainable goals.

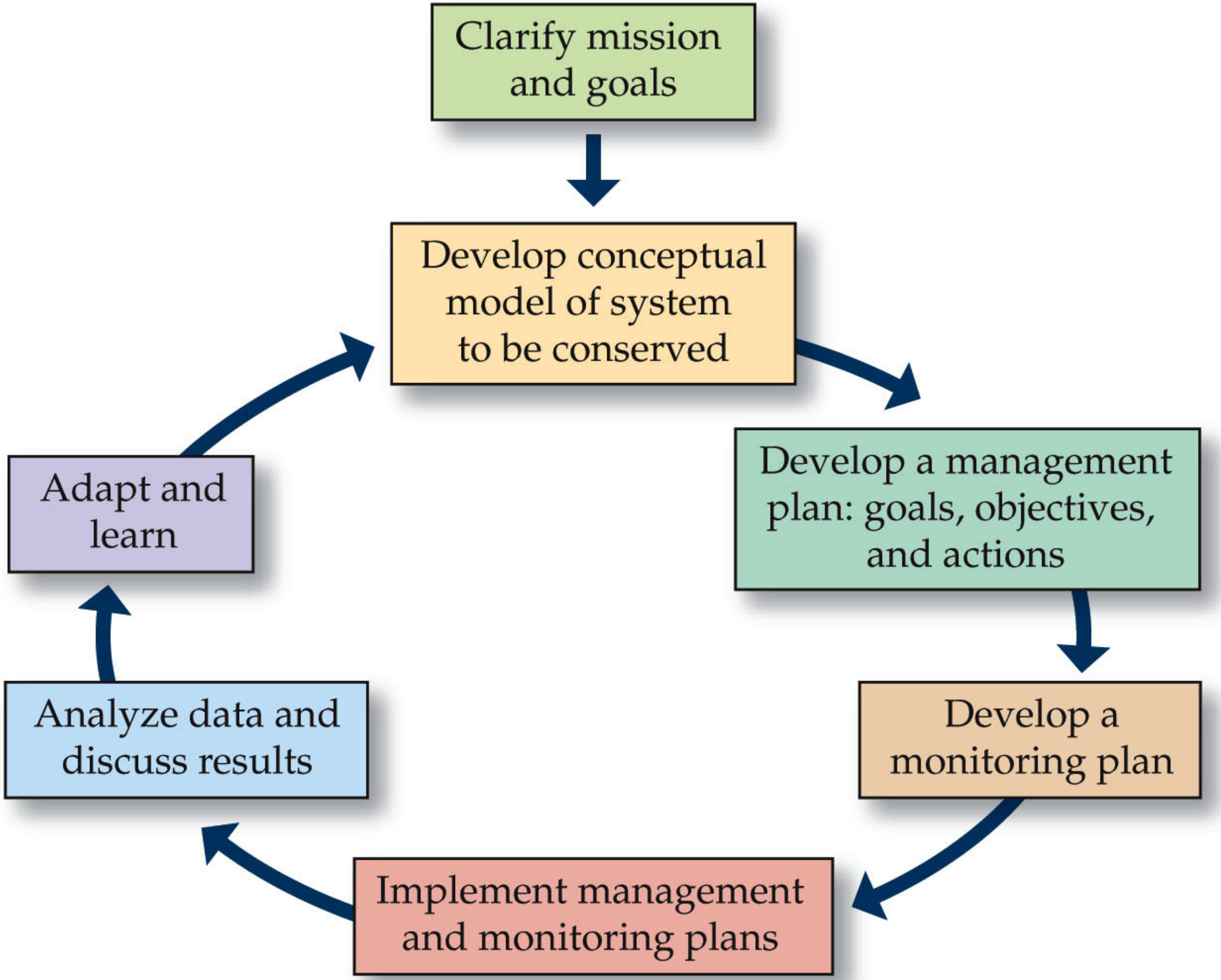
New actions, and often policies, are required.

The ecosystem is monitored to determine whether the actions bring about the desired results.

Policies can then be adjusted as needed —an iterative process known as **adaptive management.**

Example: Models that predicted the behavior of wolf and elk populations after wolf reintroduction are now being adjusted based on 10 years of data.

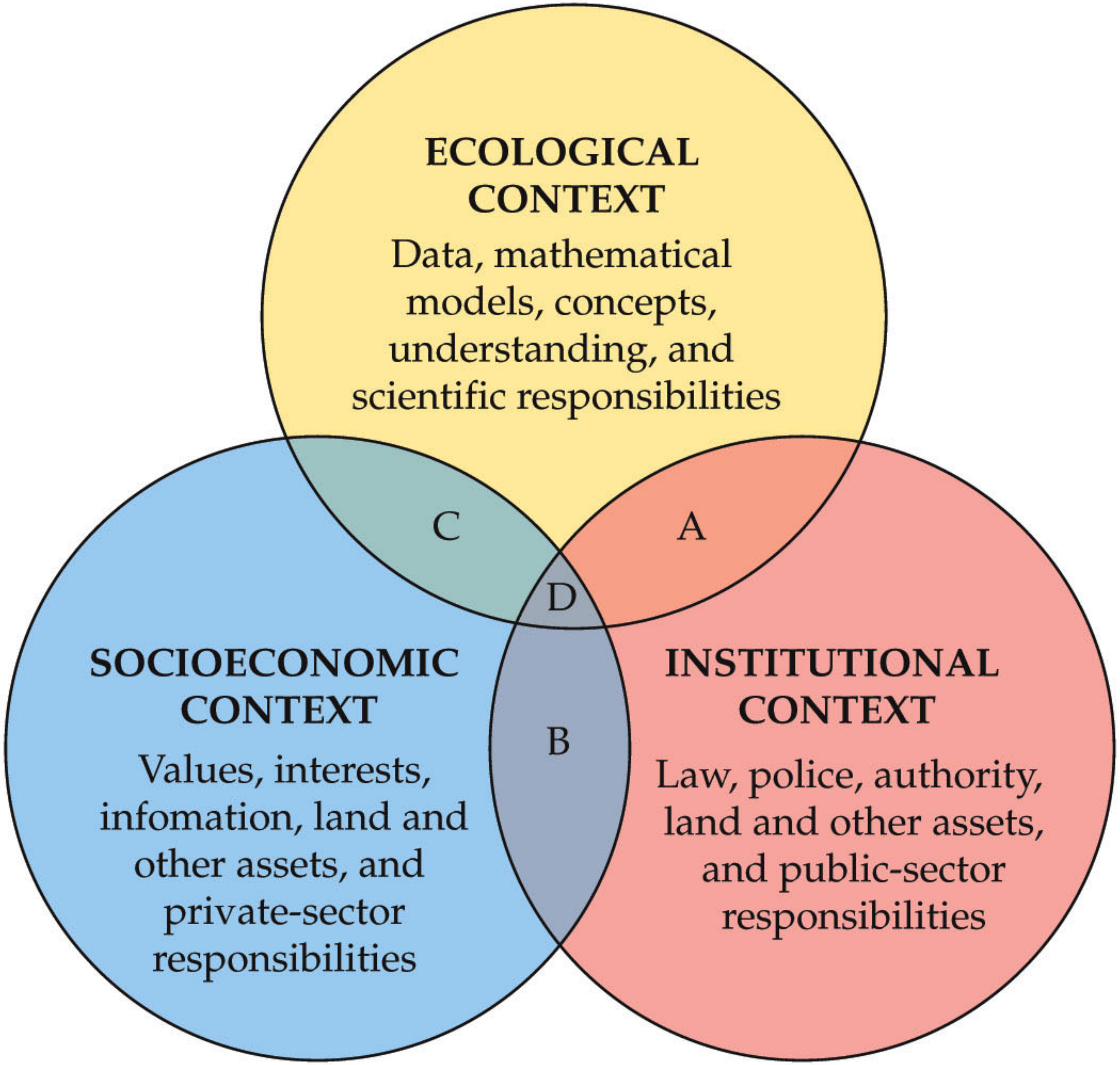
Figure 23.19 Adaptive Management Is a Vital Component of Ecosystem Management



Ecosystem management incorporates human social and economic factors as a fundamental part of the decision-making process.

The integration of different components is seen as necessary to successful management.

Figure 23.20 Humans Are an Integral Part of Ecosystem Management



ECOLOGY, Figure 23.20

Ecosystem Management

Educating the public about their reliance on ecosystem services is part of ecosystem management.

It also engages the public in helping to solve problems that degrade the ecosystem services that they rely on.

The Masoala National Park plan included a buffer zone to provide wood for the needs of people, and also identified trees with export value as part of an economic plan.

Local people and the Malagasy government were included in the planning. Local acceptance of management plans is crucial.

Case Study Revisited: Wolves in the Yellowstone Landscape

Reintroduction of wolves reflected the shift to ecosystem management.

That it happened at all reflects a quantum shift in human attitudes.

Wolves were feared and reviled, and seen as a threat to livestock. They were hunted to extinction in the lower 48 states in the 1930s.

Case Study Revisited: Wolves in the Yellowstone Landscape

With wolf removal, there were declines in riparian tree species.

Aspens failed to reproduce for 70 years, likely due to heavy browsing by elk.

31 wolves were released in 1995; they increased to 250 by 2004.

Elk were initially naive and vulnerable to predation by the wolves.

Case Study Revisited: Wolves in the Yellowstone Landscape

The elk have changed their behaviors, showing a preference for foraging in places that provide high visibility.

Aspens and other riparian trees have begun to recover in some areas.

Elk may be avoiding areas where they are most vulnerable to wolves, allowing trees in those areas to recover.

Case Study Revisited: Wolves in the Yellowstone Landscape

Recovery of riparian vegetation has had significant consequences for stream hydrology.

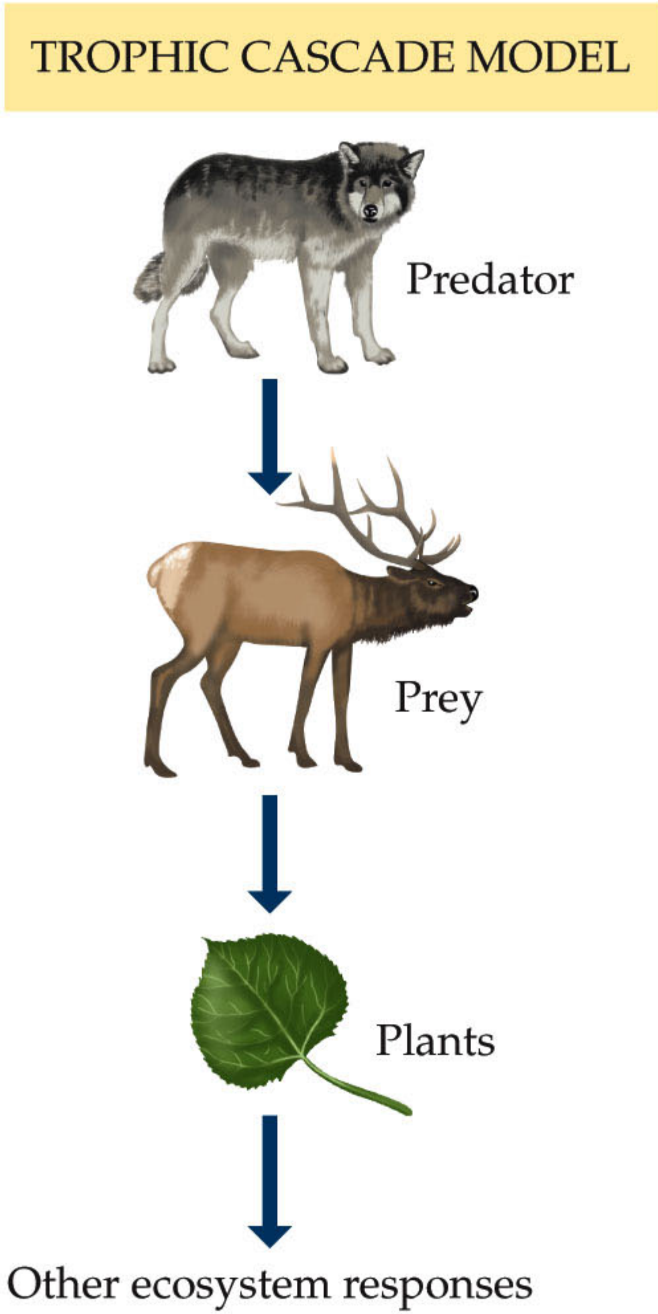
More willows lining stream banks has slowed stream flow and increased sedimentation.

Trees will also provide shade and habitat for trout and migratory birds.

Willow is the preferred food of beavers, so new beaver colonies have appeared.

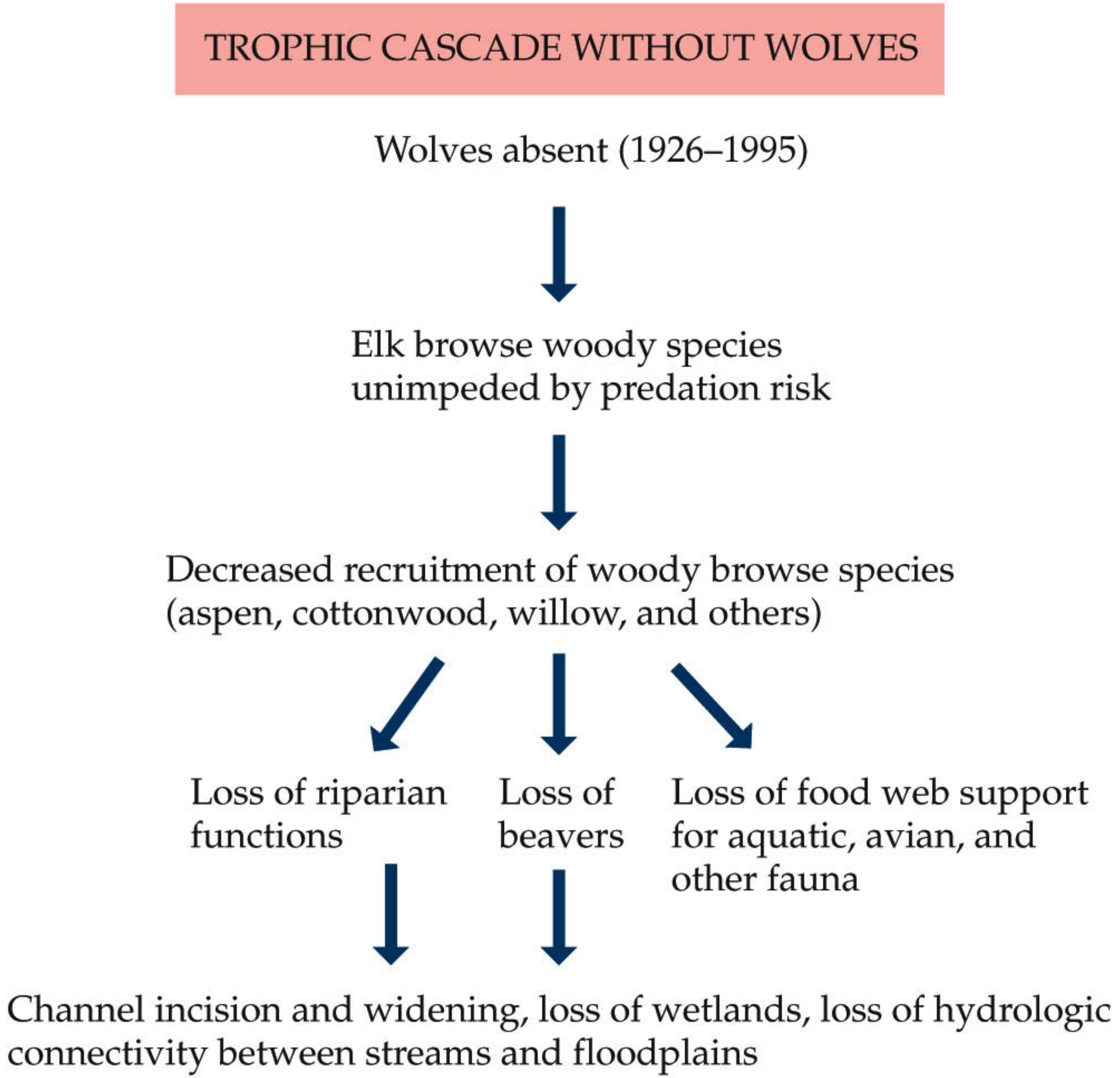
Dams built by beavers change patterns of water flow, creating marshlands that favor the return of otters, ducks, muskrats, and mink.

Figure 23.21 Trophic Consequences of Wolf Reintroduction (Part 1)



ECOLOGY, Figure 23.21 (Part 1)

Figure 23.21 Trophic Consequences of Wolf Reintroduction (Part 2)



ECOLOGY, Figure 23.21 (Part 2)

Figure 23.21 Trophic Consequences of Wolf Reintroduction (Part 3)

TROPHIC CASCADE WITH WOLVES

Wolves restored (1995)

↓

Elk foraging and movement patterns adjust to predation risk

↓

Increased recruitment of woody browse species

↓

Recovery of riparian functions

Recolonization of beavers

Recovery of food web support for aquatic, avian, and other fauna

↓

Channels stabilize, recovery of wetlands and hydrologic connectivity

ECOLOGY, **Figure 23.21 (Part 3)**

Case Study Revisited: Wolves in the Yellowstone Landscape

Clearly, wolves have the potential to change Yellowstone ecosystems.

The return of the wolf is a grand ecological experiment, one whose results will be monitored closely in years to come.

Other, fundamental changes are occurring in the Yellowstone ecosystem.

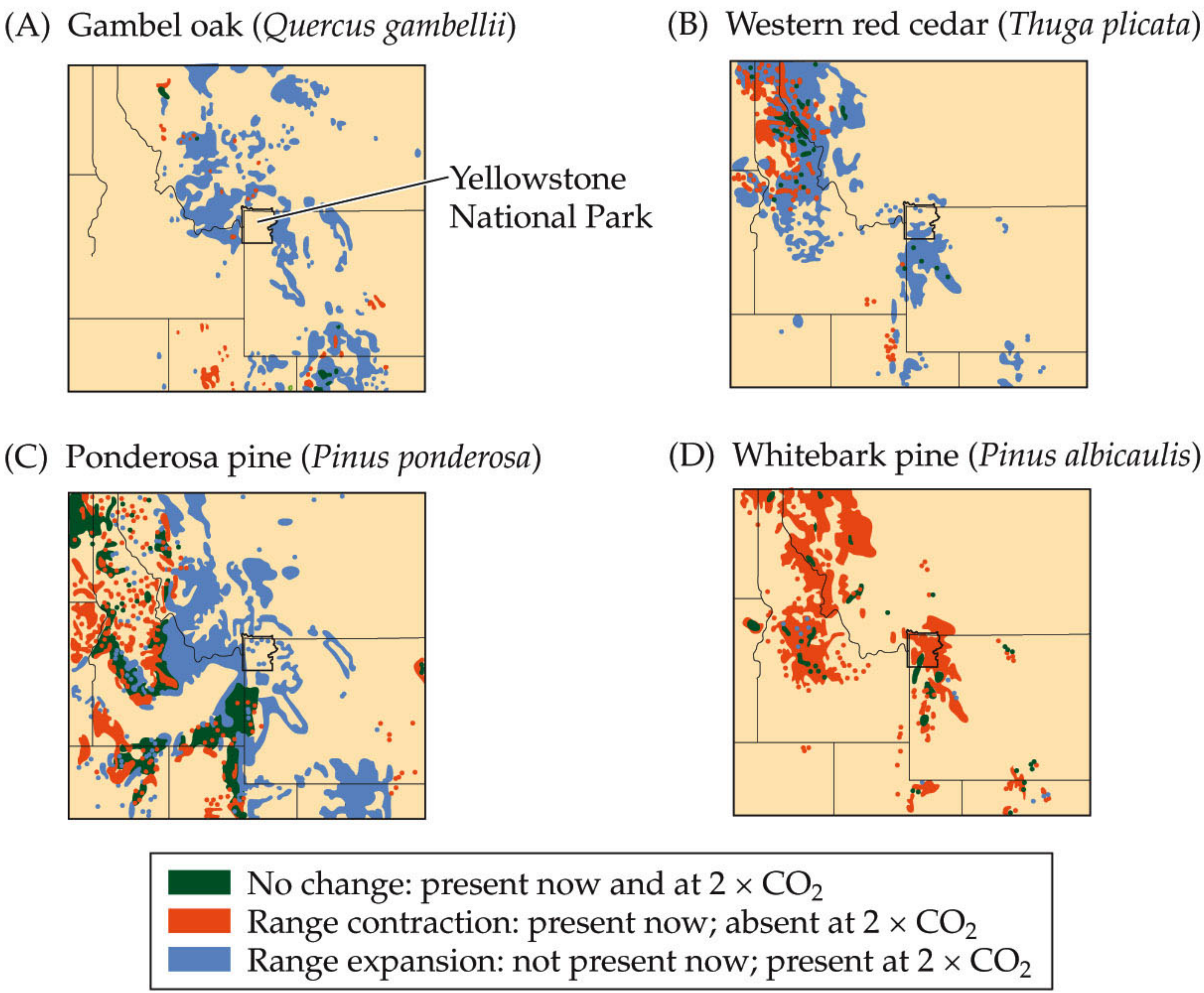
Models show what the vegetation of the region might look like under a doubling of current atmospheric CO_2 concentration, which could happen within a century.

Connections in Nature: Future Changes in the Yellowstone Landscape

Projections show higher temperatures, more frequent fires, upslope and northward migrations of many species, and shifts in forest composition.

Whitebark pine will move northward. Loss of this species may cause other ecological shifts.

Figure 23.22 Projected Effects of Climate Change in the Northern Rockies



***ECOLOGY*, Figure 23.22**

Whitebark pine is a keystone species. It produces large, fatty, nutritious nuts, a primary food source for Clark's nutcracker and both black and grizzly bears.

Clark's nutcracker disperses whitebark pine seed.

These species may also move north with the pine.

But the model cannot predict whether the movements of organisms can keep pace with climate change.

A challenge for conservation planners is to provide connectivity to enable these migrations to take place.

Effects of climate change are already being seen: Shifts in plant and animal distributions, plant phenology, and animal behavior.

Critical ecosystems that currently protect biodiversity may loose substantial area.

How can we plan for such changes and avert losses?

The tools of landscape ecology and remote sensing will be key to preparing for protection of biodiversity in the future.

The challenges will be considerable. Ecologists will have the critical role of providing the scientific information needed to make decisions. The future of untold numbers of species relies on how effective we can be at this task.