CHAPTER 9 COMMUNITY ECOLOGY

WHAT THE STORK SAYS

A bird species in the Everglades reveals the intricacies of a threatened ecosystem

CORE MESSAGE

Ecological communities are complex assemblages of all the different species that can potentially interact in an area. All the pieces of the ecological community are connected; change one thing and many others are affected. This means ecosystems are often negatively affected by human impact. Understanding the interconnections within the communities may allow us to better protect and even help restore damaged ecosystems.

GUIDING QUESTIONS

After reading this chapter, you should be able to answer the following questions:

- How does matter and energy move through ecological communities?
- How do biotic and abiotic factors affect community composition, structure, and function?
- How do species interactions contribute to the overall viability of the community?
- In what ways do human actions affect ecological communities and how can we take steps to help restore damaged ecosystems?
- How do ecosystems change over time through ecological succession? How can we use this knowledge to assist in ecosystem restoration?

Wood Storks in Florida.

James Rodgers steered his canoe toward a large cypress tree as sunlight trickled through the dizzy pattern of leaves overhead. The tree had several Wood Stork nests in it, and he and his assistant wanted to get a closer look at all of them. They were in the thick of a dense swamp near the northwestern edge of the Florida Everglades, and it was the height of breeding season for the storks—eggs had hatched and nestlings everywhere were crying, loudly, for food. Rodgers was silent. He knew from experience that alligators patrolled the waters surrounding stork nests, and that too much human disturbance could "flush" the adult storks—forcing them to flee in a hurry, which would leave their babies vulnerable to aerial predators.

The Wood Stork is an unassuming sort-of bird: more than 3 feet tall, yes. But also covered with a mottled black-and-white coat of feathers—bland compared to some of its tropical neighbors. Despite the lack of majesty of the Wood Storks, however, Rodgers and others at the Florida Fish and Wildlife Service keep close tabs on their ranks.

Here's why: In the late 1970s, the number of nesting pairs of the bird plummeted to an all-time low of 4,500 or so. By the early 1980s, the bird earned a spot on the endangered species list. It was then that Rodgers and his colleagues were first tasked with determining which of several factors (Reduced nesting habitat? Health of females? Damaged feeding grounds?) was most responsible for the decline of this particular bird. And it was through those research efforts—focused intently on the Wood Stork—that they found an entire ecosystem on the brink.

◉WHERE ARE THE FLORIDA EVERGLADES?

The well-being of a species depends on the health of its ecosystem.

Community ecology is the study of how a given ecosystem functions—how space is structured, why certain species thrive in certain areas, and how individual species in the same community interact with one another.

This includes understanding how various species contribute to ecosystem services like pollination, water purification, and nutrient cycling (see Chapter 4). Wetlands such as the Florida Everglades provide extremely important water management services, including the recharge of groundwater and the capture of contaminants and excess nutrients, enabling them to be stored or converted to safer forms. This process prevents those nutrients from reaching downstream fresh- and saltwater ecosystems. Most important to us humans, however, is the wetlands' contribution to flood control. By capturing and storing large amounts of precipitation and runoff (overland flow of water), and then releasing it downstream slowly over time, they significantly reduce peak flood levels during major rain events.

Community ecology also includes understanding the myriad ways in which we humans have altered various ecosystems, and in so doing have changed the ways they function. In the Florida Everglades, which have been heavily developed over the past half-century, infrastructure like roadways and canals have dramatically reordered the physical landscape. Meanwhile, all the pollutants that come with modern living—solid waste, agricultural chemicals, etc.—have upended the delicate balance of chemical and physical reactions that make this natural world function.

↑ The inlets of Everglades National Park contain a unique mix of tropical and temperate plants and animals, including more than 700 plant and 300 bird species.

For the Wood Stork—a tall wading bird that weighs up to 3 kilograms (7 pounds)—it's all about food. During mating season alone, the birds consume an estimated 45 kilograms (100 pounds) of food—each. One captive bird ate more than 650 small fish in just 35 minutes. Indeed, their feeding habits alone make for great spectacle. They hunt almost exclusively in shallow, muddy, plant-filled water—just 15-50 centimeters (5-20 inches) deep, but so cloudy that fish cannot be seen. They inch their way through these waters at a steady two-steps-per-second clip, sweeping their long, narrow bills—which are kept precisely 8 centimeters (3 inches) agape, and submerged all the way up to the breathing passage—side to side in a relentless hunt for food. When the bill's methodical searching meets the sensation of a wriggling fish (or crayfish), it snaps shut with spectacular speed—in just 25 milliseconds, to be exact. It's the fastest reflex known to all vertebrates, and it enables the Wood Stork to capture prey that no other wading birds can access.

community ecology The study of all the populations (plants, animals, and other species) living and interacting in an area.
indicator species The species that are particularly vulnerable to ecosystem perturbations, and that, when we monitor them, can give us advance warning of a problem.
ecosystems All of the organisms in a given area plus the physical environment in which they interact.

But for this tactile (or non-visual) feeding method to work, the prey must be densely concentrated. That means Wood Storks need seasonally drying wetlands to forage. And lots of them. Even a small drop-off in feeding success can impact the ability of these colossal birds' to successfully rear their young.

It's this sensitivity that makes the Wood Stork such a good **indicator species** for the Everglades. An indicator species is one that's particularly vulnerable to ecosystem perturbations. Because even minor environmental changes can affect them dramatically, they can warn ecologists of a problem before it grows. "It is much easier to follow one or two species than to try and monitor an entire ecosystem," says Rodgers, who is a Wood Stork specialist. "So if an indicator species can be identified, this makes it much easier to keep tabs on the health of the ecosystem."

Human alterations have changed the face of the Everglades.

South Florida once provided an ideal breeding ground for these amazing but picky birds. Before giving way to a hodgepodge of resorts, sugar plantations, and dense urban centers, the region was defined by an uninterrupted web of natural **ecosystems**, collectively known

↑ A residential community in Weston, Florida, built where Everglades once existed.

↑ Map of South Florida.

as the Everglades. Marshes, prairies, swamps, and forests stretched across some 4,000 square miles of land. Each distinct community was connected by the same slow-moving water, which began at the southern edge of Lake Okeechobee and flowed south for 100 miles before emptying into the Florida Bay. The glacial pace of this water (it can take months or even years for a given eddy to travel from lake to bay) across such a broad, shallow expanse (60 miles wide, and in some places just a few inches deep) is known as *sheet flow*. The Everglades' nickname, "River of Grass," comes from the image of sheet flow through the region's iconic sawgrass marshes.

It was here that Wood Storks flourished. In the 1930s, an estimated 15,000 to 20,000 pairs nested throughout the southeastern United States—largely in South Florida, where foraging grounds were ideal. And because their plain black-and-white plumage was not lovely enough to attract bird hunters collecting feathers for fashionable ladies' hats, the storks thrived even as other wading bird stocks were decimated.

But it was not long after they first discovered the Everglades that American explorers began hatching plans to drain and then develop them. Swamps and muddy rivers choked with grass were seen as having no inherent value. "From the middle of the 19th century to the middle of the 20th, the United States went through a period in which wetland removal was not questioned," says University of Florida geographer and historian Christopher Meindl. "In fact, it was considered the proper thing to do." The Central and Southern Florida Project, authorized by Congress in 1948, set about to systematically drain the Everglades. And over time, a vicious new cycle was established—humans would drain the swamps and replace them with towns and cities; a rash of floods would prompt more complete drainage (under the rubric of flood control and prevention), which would in turn be followed by even more development (on the newly drained land).

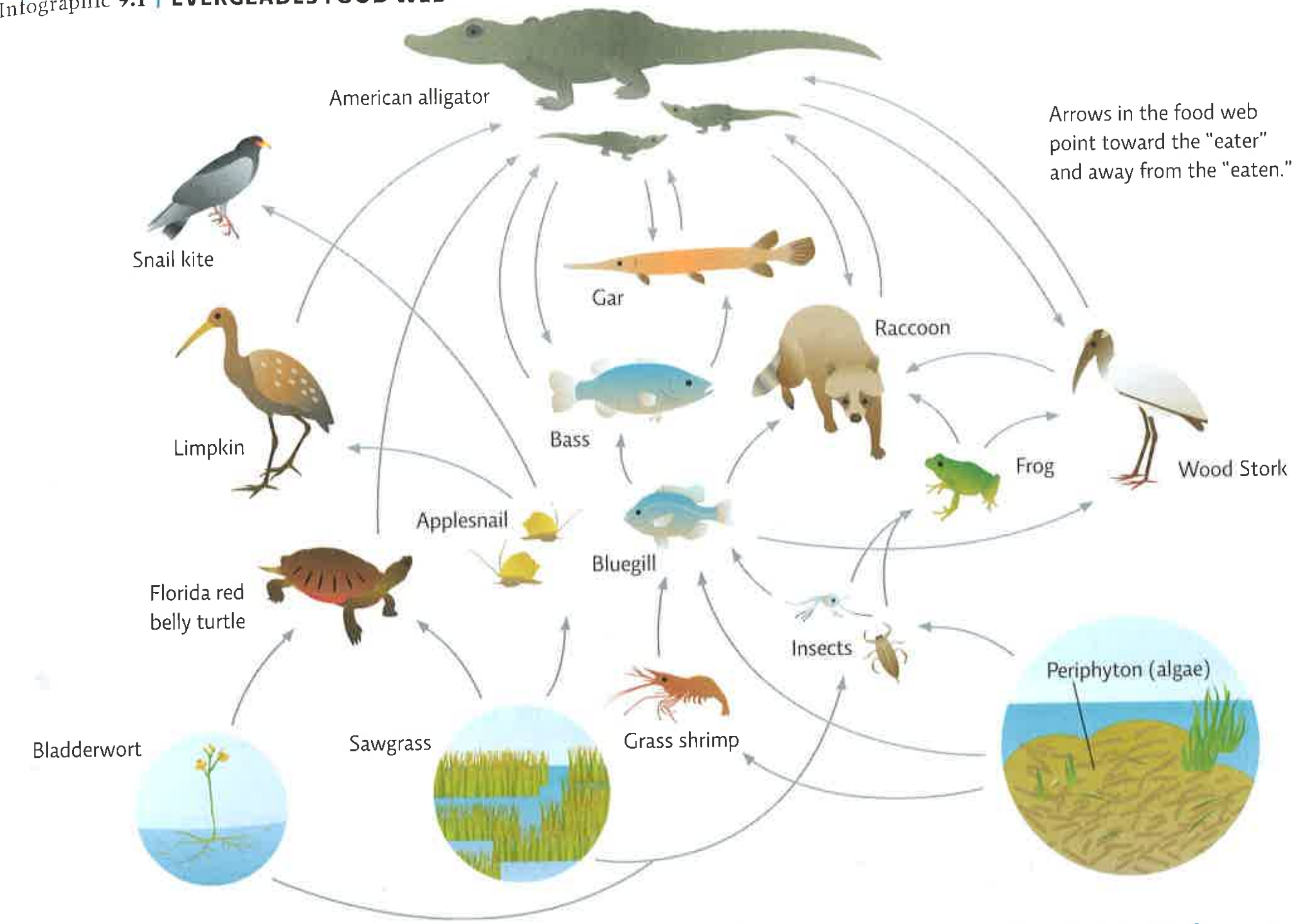
As the human population swelled in the region, water that once fed swamps and marshes was rerouted to the faucets of burgeoning developments. And as water levels changed, becoming deeper in some areas and completely disappearing in others, the total wading bird population plummeted—by 90% between the 1930s and 1990s.

Matter and energy move through a community via the food web.

As ecologists would soon discover, the loss of even one species can disrupt an entire ecosystem—from the health of giant wading birds, right down to the movement of matter and energy.

Energy is the foundation of every ecosystem; it is captured by photosynthetic organisms and then passed from organism to organism via the **food chain**—a simple, linear path that shows what eats what. Any given ecosystem might have dozens of individual food chains. Linked together they create a **food web**, which shows all the many connections in the community. Both food chains and webs help ecologists track energy and matter through a given community. They can vary greatly in length and

Infographic 9.1 | **EVERGLADES FOOD WEB**



↑ The food web of the Everglades is very complex and varies among the different ecosystems found there. Periphyton algae mats form the base of the food web and may be the most important producers in the ecosystem. The American alligator is the main apex predator, though when young is also prey to various birds, fish, mammals, and even other alligators.

complexity between different types of ecosystems. But most share a few common features and all are made up of the same basic building blocks—namely, producers and consumers. [INFOGRAPHIC 9.1]

Florida Wood Storks sit near the top of a food chain that begins with sawgrass, other plants like cypress and mangrove trees, and a mix of algae and bacteria known as periphyton. These photosynthetic organisms are all known as **producers**. Producers capture energy directly from the sun and convert it to food (sugar) via photosynthesis. They are then eaten by a wide range of **consumers**—organisms that gain energy and nutrients by eating other organisms. Animals, fungi, and most bacteria are consumers. These different feeding levels are known as **trophic levels**. Consumers are organized into trophic levels based on what they eat. *Primary consumers* eat producers; *secondary consumers* eat primary consumers; *tertiary consumers* eat secondary consumers, and so on, ending with the apex predators in the last trophic level. Of course, some organisms feed at more than one trophic level: Wood Storks eating crayfish are feeding at trophic level 3 but when they eat small fish like bluegill, they are feeding at trophic level 4.

In an ecosystem as diverse and complex as the Everglades, there are dozens of different organisms at each trophic level, making for a wide variety of food chains. For example, periphyton might be eaten by grass shrimp (a primary consumer), which in turn might be eaten by bluegill (a secondary consumer), who fall prey to raccoons

food chain A simple, linear path starting with a plant (or other photosynthetic organism) that identifies what each organism in the path eats.

food web A linkage of all the food chains together that shows the many connections in the community.

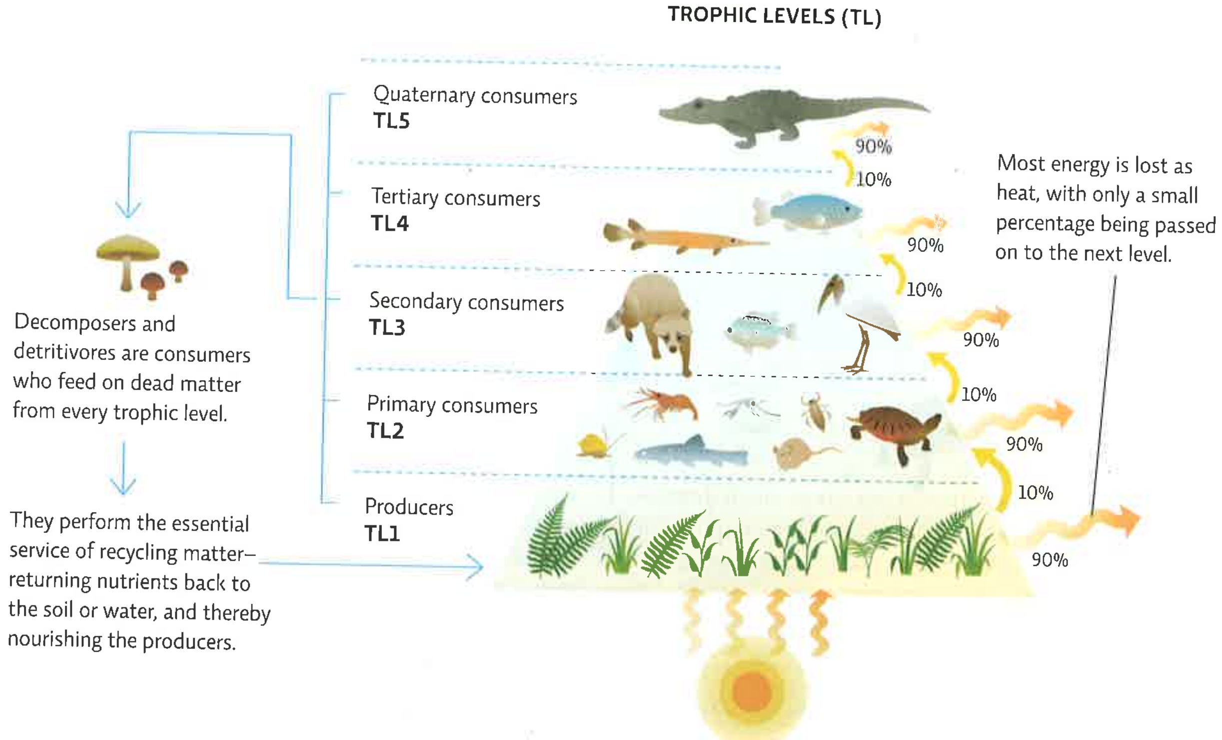
producer A photosynthetic organism that captures solar energy directly and uses it to produce its own food (sugar).

consumer An organism that eats other organisms to gain energy and nutrients; includes animals, fungi, most bacteria.

trophic levels Feeding levels in a food chain.

Infographic 9.2 | **TROPHIC PYRAMID**

↓ Energy enters at the base of the food chain in the first trophic level (TL) via photosynthesis and is passed on to higher levels as consumers feed on other organisms. This is shown as a pyramid (smaller on top) because only about 10% of the energy is passed on to each subsequent level, with the other 90% being "lost" to the environment (usually as heat from the energy that the organism burns in day-to-day life before it is eaten). Most food chains have only 4 or 5 levels due to this progressive loss of energy.



(tertiary consumers), who might be eaten by alligators (quaternary consumers). Alligators eat a wide variety of animals—turtles, fish, birds, even mammals like the raccoon—making them the apex predator in many Everglades food chains.

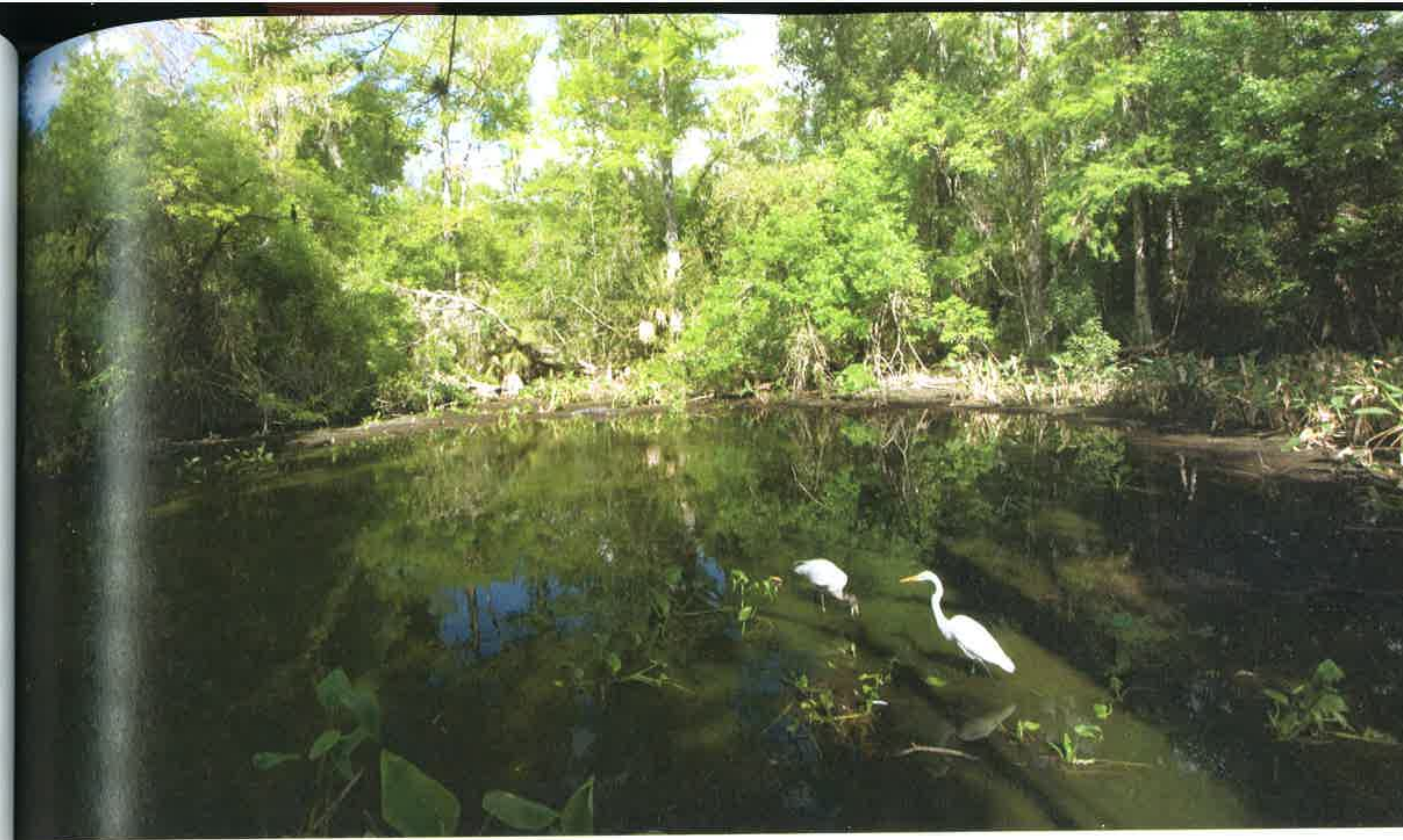
When any of these organisms die, they are eaten by an army of consumers known as **detritivores**—animals like worms, insects, and crabs, that feed on dead plants and animals—and **decomposers**—organisms like bacteria and fungi that break decomposing organic matter all the way down into its constituent atoms and molecules.

As one moves up the food chain, energy and *biomass* (all the organisms at that level) decrease, creating a trophic pyramid. The reason is simple: Nearly every organism uses up the majority of its energy and matter in the complicated act of living. So when it is killed and consumed by a predator, it only passes on about 10% (some species pass on more or less than others) of all the energy and matter it consumed during its lifetime. [INFOGRAPHIC 9.2]

A pyramid's ultimate size is determined by its first trophic level—the one made up of photosynthesizing producers, namely plants. More plant growth means more food for primary consumers, which in turn means more food for those organisms above them, and so on up the food chain. The end result is a larger pyramid with more and larger trophic levels.

Productivity—the amount of energy trapped by producers and converted into organic molecules like sugar—is limited by sunlight and nutrient availability. **Gross primary productivity** is a measure of total photosynthesis. But plants only use a portion (actually less than 50%) of this energy to fuel their daily needs. Scientists use the term **net primary productivity (NPP)** to describe how much energy is left over after that. The "net" is a measure of energy available to higher trophic levels—in other words, the amount that's converted to new growth.

The Everglades are blessed with long summer days that favor plant and algal photosynthesis. But in many other ecosystems, winter months cast the downside of sunlight dependence into stark relief. In most temperate and boreal forests, for example, less sunlight and cooler temperatures limit photosynthesis during these months, causing plant productivity to slow, or shut down completely,



↑ Great White Egret and Wood Stork feed in shallow ponds and channels (called sloughs) in a glade in Everglades National Park.

resulting in less new growth, and thus less food for other organisms. This is why bears hibernate and birds fly south for the winter: The lack of productivity drives them to these extremes. NPP can be a window into the health of an ecosystem. If it rises or falls unexpectedly, ecologists can look for the cause of the change, which might be an invasion by a non-native plant or a sudden drop in a producer population. Anything that alters NPP can potentially affect organisms at every other level of the trophic pyramid.

As researchers discovered back in the 1980s, it was a kink in the food chain that hurt the Wood Storks. While they feed on many things, they prefer fish—and not just any fish, but those between 2 and 15 centimeters (1 and 6 inches) long. Most fish need more than a single season to grow this big; in fact, they need wetlands that are flooded for longer than a year and only very rarely go completely dry. It turns out that as humans altered water cycles in South Florida, there were fewer and fewer such areas, and thus fewer fish for the storks to feed their young.

The Everglades are shaped by biotic and abiotic factors.

Much of Florida is made up of low, flat land that floods from June through September. During this period, Florida typically receives about 75% of its annual rainfall; water forms a vast sheet, covering thousands of acres, and small changes in depth can amount to large changes in surface area. Many wetland fish grow and reproduce in this expanding habitat. Then, as rains taper off, water begins to recede. And where they were once spread out, fish become concentrated in small ponds and *sloughs* (free-flowing channels of water that develop in between sawgrass prairies). Foraging storks follow these receding waters, which ecologists like to call "dry down," from upland ponds to lowland coastal areas, feeding on fish as they become concentrated. They are so dependent on this water cycle, studies show, that their breeding cycle is regulated by water levels. Such profound connectedness—between landscape and life—is common in the Everglades.

detritivores Consumers (including worms, insects, crabs, etc.) who eat dead organic material.

decomposers Organisms such as bacteria and fungi that break down organic matter all the way down to constituent atoms or molecules in a form that plants can take back up.

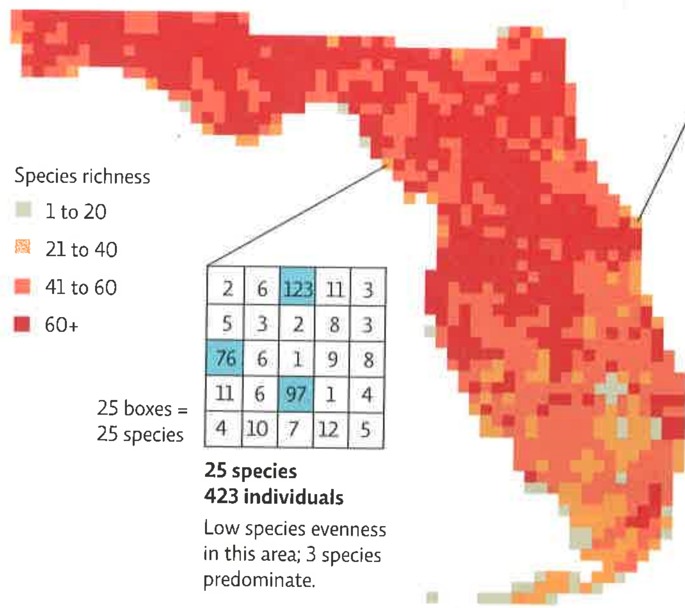
gross primary productivity A measure of the total amount of energy captured via photosynthesis and transferred to organic molecules in an ecosystem.

net primary productivity (NPP) A measure of the amount of energy captured via photosynthesis and actually stored in the photosynthetic organism.

Infographic 9.3 | **MEASURING SPECIES DIVERSITY**

The species diversity in an area is a measure of species richness (the total number of species) and species evenness (a comparison of the population size of each species). To survey birds in the state, the Florida Fish and Wildlife Conservation Commission divides the state into more than 1,000 "blocks" and records the number of bird species seen in each; their 1998 data is shown here. Lower diversity is seen in areas with more homogeneous habitats such as sand pine forests or agricultural areas, as well as in areas that are more developed.

In a hypothetical comparison of two of those blocks, one on the west coast and one on the east coast, let's say both blocks have 25 bird species. The number of individuals seen for each species is shown in a 25-box grid. We see that both areas have the same number of individuals overall (423); however, in our example, the east coast block has much greater species evenness than the west coast block. Therefore the east coast block is considered to have greater overall species diversity than the west coast block.



25 boxes = 25 species

2	6	123	11	3
5	3	2	8	3
76	6	1	9	8
11	6	97	1	4
4	10	7	12	5

25 species
423 individuals

Low species evenness in this area; 3 species predominate.

20	18	15	16	22
15	22	14	12	18
11	23	18	16	13
20	18	14	15	22
12	26	19	11	19

25 species
20 + 18 + 15 + 16... = 423

High species evenness in this area; about the same number of individuals of each species is present.

Such connections among species, and between species and their environment, give rise to *ecosystem complexity*. Ecosystem complexity is a measure of the number of species at each trophic level, as well as the total number of trophic levels and available niches. Each species occupies a unique **niche**—that is, a unique role and set of interactions in the community, how it gets its energy and nutrients, and its preferred **habitat**. If two different species tried to occupy the same exact niche, one would outcompete the other. The less successful species has three choices: leave the area, switch niches, or die out. Greater ecosystem complexity means more niches and thus more ways for matter and energy to be accessed and exchanged. This generally increases a community's **resilience**—its ability to adjust to changes in the environment and return to its original state rather quickly.

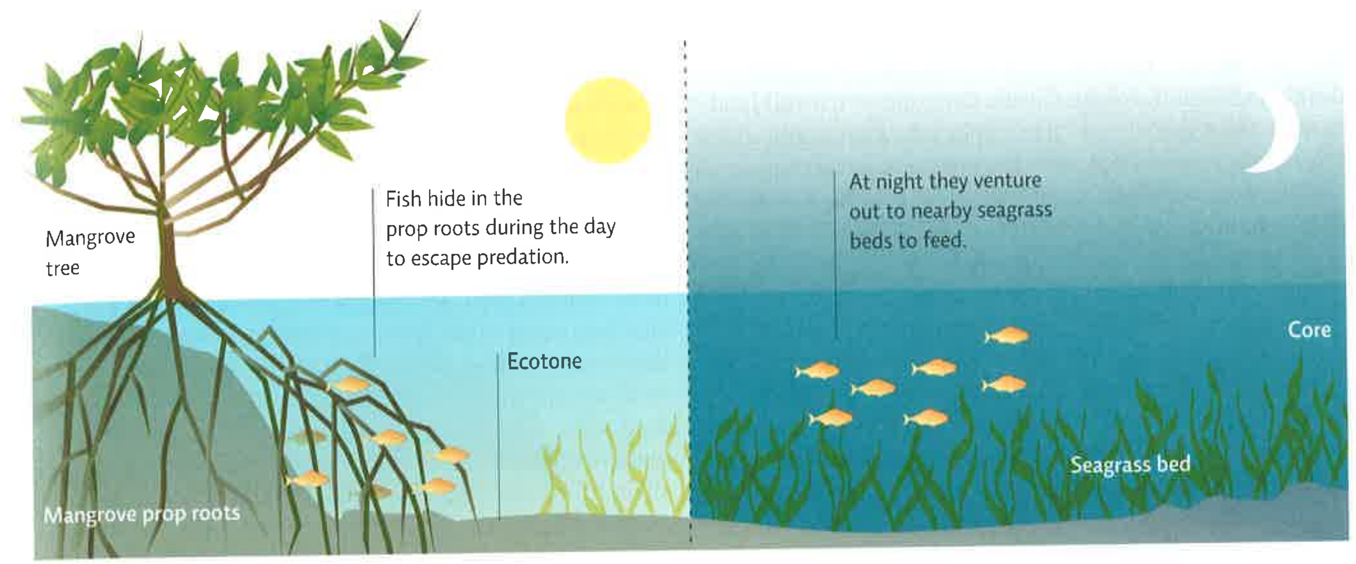
Species diversity, which refers to the variety of species in an area, is measured in two different ways: species richness, and species evenness. **Species richness** refers to the total number of different species in a community. **Species evenness** refers to the relative abundance of each individual species. In general, organisms at a higher trophic level will have fewer members than those at a lower trophic level, but organisms within the same trophic level should have relatively similar numbers. If they do, the community is said to have high species evenness. If, on the other hand, one or two species dominate any given trophic level, and there are few members of other species, then the community is said to have low species evenness. In such uneven communities, the less abundant species is at a greater risk of dying out.

Both richness and evenness have an impact on diversity. In general, higher species richness and evenness makes for a more complex community and a more intricate food web. It enables more matter and energy to be brought into the system and also makes the community less likely to collapse in the face of calamity. [INFOGRAPHIC 9.3]

A community's composition, and thus complexity, is also heavily influenced by its physical features. As physical features like temperature and moisture change, so does community composition. This often happens in **ecotones**, places where two different ecosystems meet—like the edge between a forest and field, or river and shore. The different physical makeup of these edges creates different conditions, known as **edge effects**, which either attract or repel certain species. For example, it is drier, warmer, and more open at the edge between a forest and field than it is further into the forest. This difference produces conditions favorable to some species but not others.

Infographic 9.4 | **MANGROVE EDGES**

The mangrove–seagrass ecotone provides an example of an edge effect. Fish such as immature gray snapper and bluestriped grunt "commute" between the mangrove trees and the seagrass beds. The proximity of these two areas is vital to provide both the protection during the day and feeding opportunities at night that these young fish need.



Ecotones may also attract some species that use different aspects of the two adjacent communities; fish such as young snapper or grunts, for example, prefer to live in areas where seagrass beds are fairly close to a shoreline populated by mangrove trees. The mangrove "prop" roots, which anchor the trees into the wet, sandy ground below, offer the fish safety from predators during the day but are close enough to the seagrass beds where the snapper and grunts feed at night for easy "commuting." These fish are not found in coastal areas without the combination of protective coastal mangrove trees and close-by, offshore seagrass beds. [INFOGRAPHIC 9.4]

Species that thrive in edge habitats like this are called **edge species**. Other species, those that can only be found deep within the core of a given habitat, are called **core species**. Some of the many species who find food and refuge in the seagrass, such as crustaceans, sea urchins, and worms, prefer to stay in core areas where they are better hidden and protected from wave action or can make use of deeper sediment buildup in these inner areas. Because they will not venture out across the edge in search of new habitat, core species are easily trapped by habitat fragmentation; we may eliminate the species altogether if we don't leave enough core area behind. (See Chapter 12 for more on habitat fragmentation and core species.)

niche The role a species plays in its community, including things like how it gets its energy and nutrients, what habitat requirements it has, and which other species and parts of the ecosystem it interacts with.

habitat The physical environment in which individuals of a particular species can be found.

resilience The ability of an ecosystem to recover when it is damaged or perturbed.

species diversity The variety of species in an area; includes measures of species richness and evenness.

species richness The total number of different species in a community.

species evenness The relative abundance of each species in a community.

ecotones Regions of distinctly different physical areas that serve as boundaries between different communities.

edge effects The different physical makeup of the ecotone which creates different conditions that either attract or repel certain species (for instance, it is drier, warmer, and more open at the edge of a forest and field than it is further in the forest).

edge species Species that prefer to live close to the edges of two different habitats (ecotone areas).

core species Species that prefer core areas of a habitat—areas deep within the habitat, away from the edge.

Changing community structure changes community composition.

Wood Storks are spectacular fliers. From a perch, they spring their giant bodies into air in a single motion, then extend their necks and legs fully as they take flight. They can reach altitudes as high as 1,500 meters (5,000 feet), and can glide for miles without flapping their wings (a feat accomplished by riding vertical air currents: The currents support their weight and allow the storks to spiral upward). When foraging grounds dry up, or flood, or are converted into human developments, these aerial skills are pushed to the limit. Surveys showed some Wood Storks flying farther and farther from their nesting habitat in search of foraging grounds—as much as 120 kilometers (75 miles) in some cases.

But they weren't the only ones to struggle in the newly developed region. As the Florida Everglades' natural landscape was modified—as cities replaced swamps and roads replaced rivers—so too were the species interactions and thus the composition of the natural communities that remained.

Dams, dikes, and bridges installed to give humans total control over water levels—in any given portion of the Everglades at any given time—disrupted the flow of water like never before—causing some portions of the Everglades to stay too wet for too long, and others to stay far too dry. As sloughs ran dry, key detritivores and decomposers like worms, grass shrimp, and microbial communities that had thrived there were decimated. This then led to the decline of the snakes, fish, alligators, turtles, and wading birds that fed on them.

Meanwhile, agricultural lands—sugar plantations, in particular—were doing as much damage as flood control efforts. The Everglades are a nutrient-poor ecosystem, especially low in phosphorus. This is fine for the plants and animals that live there; they have evolved and adapted to such conditions and are very effective at moving nutrients through the food chain. But, as early developers discovered, it's not so good for agriculture. To grow crops, farmers must add large quantities of synthetic nutrients to the mucky wetland soil. The runoff from those nutrients has created vast algal blooms, from Lake Okeechobee and elsewhere, which have in turn choked off plant and animal life. As scientists recently discovered, phosphorus runoff is flushed into the canals, then pumped into the lake. When the lake drains, the phosphorus enters marshes and trickles through other ecosystems, changing nutrient levels, and plant species composition along with it.

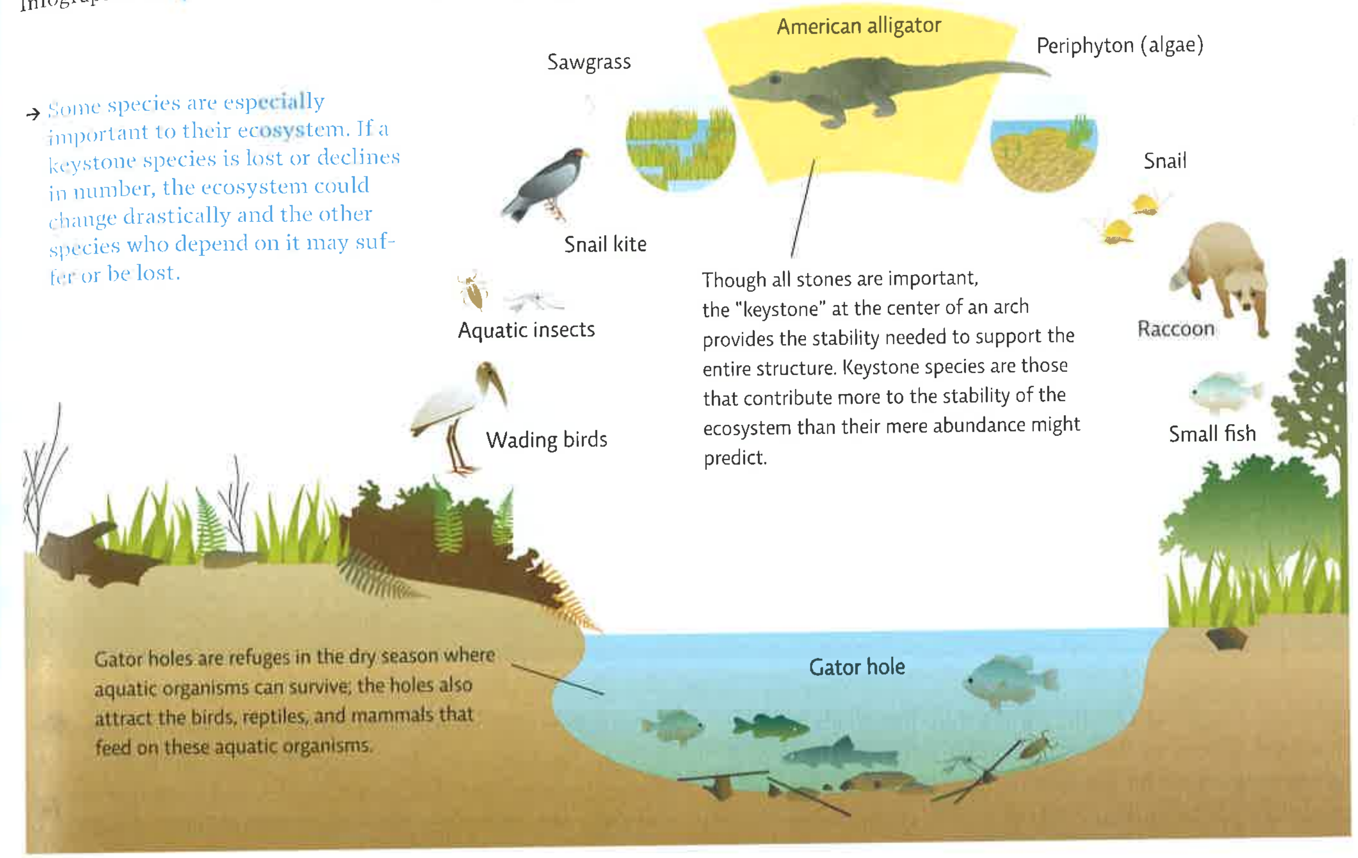
Sawgrass, typically the dominant species in the marsh, is well adapted to obtain phosphorus from the normally nutrient-poor waters. Cattails, another Everglades producer species with unique flowering spikes, normally prefer the marshes' edges, its growth limited by the lack of phosphorus. However, Danish ecologist Hans Brix and his colleagues have shown that when phosphorus levels increase, cattails can quickly outcompete sawgrass. In the experiment, both plants took in more phosphorus from nutrient-enriched waters. But cattails increased their phosphorus uptake ten-fold, whereas sawgrass increased theirs only five-fold. This allows the cattails to grow more quickly than sawgrass. In areas with nutrient enrichment, they have pushed beyond their natural habitat, through ecotones and into neighboring communities, where they now grow in such dense mats that they're outcompeting sawgrass, choking off native invertebrates on the bottom of the food chain, and physically preventing birds and alligators from nesting. (See Chapter 7 for more on nutrient cycles.)

Replacing mangrove forests with oceanfront resorts has also proven problematic. It turns out that mangrove trees are a **keystone species**—one that impacts its community more than its mere abundance would predict. It's a species that many other species depend on, and one whose loss creates a substantial ripple effect, disrupting interactions for many other species, and ultimately, altering food webs. From their natural habitat at the water's edge, mangrove "prop roots" stabilize the shoreline and provide shelter for a wide variety of fish. So when the mangrove forests are cleared, many other species suffer: the fish that hide among their roots, the fish that feed on those fish, and so on.

Alligators are also a keystone species in the Everglades, one that a great many species depend on during the dry season. As the waters recede, depressions made by alligators (gator holes) are some of the few places that still hold standing water. These holes become refuges for fish, invertebrates, and aquatic plants; they also become very attractive to the animals who feed on these aquatic creatures. Without gator holes, many species would not survive the dry season.

Wood Storks also depend on the presence of alligators, but not just for the dry season gator holes. Back in the 1980s, Rodgers and his colleagues embarked on a comprehensive study of stork nests in an effort to see which types of trees the storks preferred to nest in, and whether or not the availability of those trees was impacting their ability to breed. "We went to 20 stork colonies," Rodgers remembers. "We measured every tree, recorded its species, size, cored it for age, noted its branching structure." The results, arrived at after 5 years of painstaking work, can be summed up in a single sentence, Rogers says: Wood Storks will nest in just about anything, as long as it's surrounded by water that is patrolled by alligators. "Without the alligators, raccoons swim across, and climb up and destroy everything," Rogers says. "Without the alligators, when predators get in, we've seen them abandon entire colonies." [INFOGRAPHIC 9.5]

Infographic 9.5 | KEYSTONE SPECIES SUPPORT ENTIRE ECOSYSTEMS



Species interactions are extremely important for community viability.

Communities are all about relationships. Successful communities are those where a certain balance has evolved between all the organisms living there. Species interactions serve many purposes; for example, they control populations and affect carrying capacity. Biodiversity (lots of species, lots of variety within a species) is important, because more diversity means more ways to capture, store, and exchange energy and matter. But it is not sheer numbers that matter most; it is all the connections between species—how they help or hurt one another—that determine how and how well an ecosystem works. Each species is unique and thus interacts in its own unique way with all the species around it.

Many of the species have adaptations that bind them to others or that allow them to coexist. In the Everglades, for example, alligators have adaptations—like sharp teeth and powerful jaws—that allow them to stalk and capture prey while most of the fish that they prey on have adaptations—like camouflage and a wary nature—that help them avoid capture.

Competition—the vying between organisms for limited resources—is another way that species interact. In general, it is subtle, rather than outright fighting. **Intraspecific competition** (that which occurs between members of the same species) is generally stronger than **interspecific competition** (that which occurs between members of different species). This is because members of the same species share the exact same niche and thus compete for all resources in that niche, whereas members of different species may compete for only a single resource, like water.

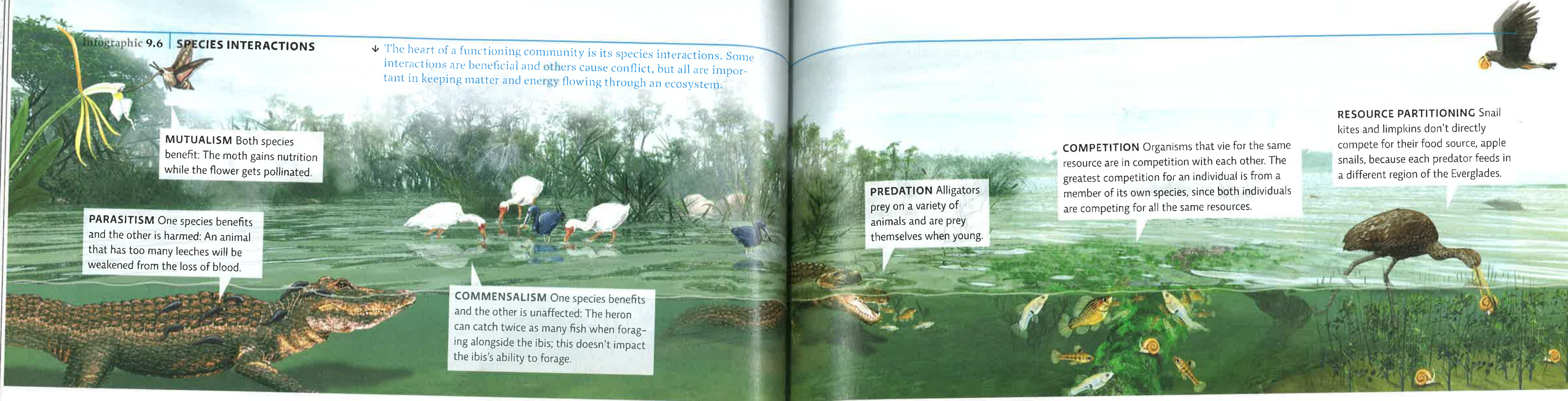
Other neighbors—those who prey on the same food, or inhabit similar niches—find a way to partition resources. That is, they divvy up the goods in a way that reduces competition and allows several species to coexist. For

keystone species A species that impacts its community more than its mere abundance would predict.

competition Species interaction in which individuals are vying for limited resources.

intraspecific competition Competition between members of the same species.

interspecific competition Competition between individuals of different species.



Infographic 9.6 | **SPECIES INTERACTIONS**

The heart of a functioning community is its species interactions. Some interactions are beneficial and others cause conflict, but all are important in keeping matter and energy flowing through an ecosystem.

example, limpkins and snail kites (two Everglade birds that feed almost exclusively on apple snails) hunt in different regions of the Everglades. This strategy—known as **resource partitioning**—increases the ecosystem's overall capture of matter and energy and thus benefits the entire community.

There are other strategies, too, that keep an ecosystem functioning and strong. Some of these interactions show a tremendous interdependency on the part of the participants. Known as **symbiosis**, these relationships can take one of three forms: **mutualism**, where both parties benefit; **commensalism**, where one benefits from the relationship but the other is unaffected; and **parasitism**, where one benefits from the relationship and the other is negatively affected (this is actually a form of predation). [INFOGRAPHIC 9.6]

resource partitioning When different species use different parts or aspects of a resource, rather than competing directly for exactly the same resource.
symbiosis A close biological or ecological relationship between two species.
mutualism A symbiotic relationship between individuals of two species in which both parties benefit.
commensalism A symbiotic relationship between individuals of two species in which one benefits from the presence of the other but the other is unaffected.
parasitism A symbiotic relationship between individuals of two species in which one benefits and the other is negatively affected (a form of predation).
restoration ecology The science that deals with the repair of damaged or disturbed ecosystems.

By ensuring that all populations persist, even as individuals die, these delicate checks and balances allow more energy to be captured and exchanged, and thus increases the amount of biomass the ecosystem is able to produce.

As we've seen, the Wood Storks rely on several relationships to survive. Their ability to feed depends not only on very specific wetlands hydrology, but also on the health and size of the fish they feed upon. And their ability to raise and fledge young depends not only on the availability of "moated" trees—those surrounded by water—but also on a healthy population of alligators that can patrol those moats for raccoons. When individual species are lost, or when a landscape is physically altered, the balance is tipped. And when that happens, things can fall apart. Fast.

Ecologists and engineers help repair ecosystems.

The federal 1992 Water Resources Development Act enlisted the U.S. Army Corps of Engineers to investigate the damage to the Everglades that resulted from nearly 50 years of unchecked expansion. The final report, published in 1999, acknowledged that the original Everglades (as we found them upon first exploration in the late 1800s) had been reduced by 50%. Constructed canals and levees had dramatically altered water levels, leaving some areas parched and others flooded. And poorly timed water releases were further starving ecosystems that had already been affected by hypersalinity, excessive nutrients (from agricultural runoff), and an ever-growing list of non-native species.

Ignoring these problems any longer could greatly imperil the 10 million people that had made their home in the region. "What folks finally realized when we reexamined the area was that the wetlands were this essential filter—they cleaned the water of pollutants," says Kim Taplin, a restoration ecologist who works for the U.S. Army Corps of Engineers restoring the Florida wetlands. "So as the ecosystems have suffered, water quality has declined considerably. We're going to have millions of people with no clean water, unless we fix it." Fixing it is the work of restoration ecologists. **Restoration ecology** is the science that deals with the repair of damaged or disturbed ecosystems. It requires a special blend of skills—not only biology and chemistry, but also engineering and a heavy dose of politics.

> "We're going to have millions of people with no clean water, unless we fix it." —Kim Taplin

In 2000, the U.S. Congress enacted the most comprehensive—and expensive—ecological repair project in history. The Comprehensive Everglades Restoration Plan, or CERP, included more than 60 construction projects to be completed over a 30-year period. The idea was to restore some of the natural flow of water through the Everglades and to capture a portion of the water that now flows to the ocean for South Florida cities and farms.

One of the Army Corps' biggest challenges has been to take down at least part of the Tamiami Trail, a 240-kilometer (150-mile) stretch of U.S. highway that connects the Southern Florida cities of Tampa and Miami. The road, which was built in the 1920s, has proven itself one of the most serious barriers to freshwater flow in the region. It's also a heavily traveled, essential piece of human infrastructure that connects two major cities. That means the U.S. Army Corps must not only tear the road down, but also build something in its place. "Most of our restoration projects involve building even more structures," says Tim Brown, project manager for the U.S. Army Corps of Engineers' Tamiami Trail project. "It's a delicate balance. We of course want to restore as much of the natural system as possible. But we are also charged with protecting lives and property, and in this case, that means building bridges."

Tamiami is not the only plan in the works. In 2008, the state of Florida agreed to buy U.S. Sugar Corporation and all of its manufacturing and production facilities in the Everglades Agricultural Area south of Lake Okeechobee for roughly $1.7 billion. State officials declared that they would allow U.S. Sugar to operate for 6 more years before shuttering facilities and beginning the work of restoration. After that, water flow from Lake Okeechobee would be funneled through a series of holding and treatment ponds that would release clean water into the

Infographic 9.7 **THE COMPREHENSIVE EVERGLADES RESTORATION PLAN**

↓ Darker-green areas represent wetland areas or river floodplains; white arrows show overland water flow.

HISTORIC FLOW

↑ Historically, the Everglades covered most of South Florida—more than 10,000 square kilometers (4,000 square miles).

CURRENT FLOW

↑ Projects to drain the wetlands and divert water to agricultural lands disrupted normal flow, drained about half of the wetlands and ended up resulting in water shortages for the downstream ecosystems and for people as well.

PROPOSED FLOW UNDER CERP

↑ The goal of the Comprehensive Everglades Restoration Plan (CERP) is to restore the flow of water back to some historic wetland areas through the removal of some canals and levees, as well as to capture some of the freshwater that drains into the ocean, benefiting both the ecosystems and the residents of South Florida.

↑ Michael Korvela, of the South Florida Water Management District, with vegetation from an artificial marsh in Palm Beach, Florida, that filters pollutants from water bound for the Everglades.

Everglades, rehabilitating some 187,000 acres of land. But the agreement has been revised several times since then as the economy has fluctuated and state officials and sugar executives have adjusted and readjusted exactly how many acres would be bought for exactly how many dollars. The proposed purchase was hotly debated, as many feared the cost would take money away from other Everglades restoration projects. In October 2010, just under 27,000 acres were purchased for $197 million, with a 10-year option to acquire another 153,000 acres. A year later, U.S. Sugar was still farming the land, leasing it back from the state.

Each facet of CERP has brought its own fresh round of debate over how best to balance the needs of a swelling human population against the importance of restoring and protecting a heavily degraded ecosystem. Of course, no one knows for certain what will work and what won't. The Everglades landscape has changed dramatically, in ways that not even the best scientists can reverse; decades of development will do that. To plan effective restoration efforts, then, scientists and engineers must be flexible; they must be willing to experiment and respond as conditions change—an *adaptive management* approach similar to that used to address stratospheric ozone depletion (see Chapter 2). [INFOGRAPHIC 9.7]

"The bottom line, though, is that there's only so much we can do," says Rodgers. "It's a lot just to figure out what the baseline was or should be. Some plant species have probably gone extinct, and some non-natives are virtually impossible to remove. What we can do is figure out what some of the big obstacles to recovery are, remove them, and after that, let nature take its course." For his part, Rodgers says he can't imagine that the great 1,000-breeding-pair Wood Stork colonies that early settlers described will ever return to South Florida. The landscape has been too dramatically altered, he says. Though sometimes, of course, nature can surprise us.

Community composition changes over time as the physical features of the ecosystem itself change.

Though the changes the Everglades have experienced are extreme, changes to ecological communities are really the norm—nature is not static. Predictable transitions can sometimes be observed in which one community replaces another, a process known as **ecological succession**. **Primary succession** begins when **pioneer species** move into new areas that have not yet been colonized. In terrestrial ecosystems, these pioneer species are usually lichens—a symbiotic combination of algae and fungus. Lichens can tolerate the barren conditions. As time goes by and they live, die, and decompose, they produce soil. As soil accumulates, other small plants move in—typically sun-tolerant annual plants that live one year, produce seed, and then die—and the plant community grows. Gradually, the plant growth itself changes the physical conditions of the area—covering sun-drenched regions with broad, shady leaves, for example. Since these conditions are no longer suitable for the plants that created them, new species move in and those changes beget even more changes until the pioneers have been completely replaced by a succession of new species and communities.

Secondary succession describes a similar process that occurs in an area that once held life but has been damaged somehow; the level of damage the ecosystem has suffered determines what stage of plant community moves in. For example, a forest completely obliterated by fire may start close to the beginning with pioneering lichens, whereas one that has suffered only moderate losses may start midway through the process with shrubs or sun-tolerant trees moving in. The stages are roughly the same for any terrestrial area that can support a forest: first annual species, then shrubs, then sun-tolerant trees, then shade-tolerant ones. Grasslands follow a similar pattern with different species of grasses and forbs (small leafy plants) moving in over time.

We tend to view this progression as a "repair" sequence. While we can certainly step in to assist in this natural progression to help a damaged ecosystem recover to a former state, the ecosystem is simply doing what comes naturally—responding to changing conditions.

Intact ecosystems have a better chance at recovering from, and thus surviving, perturbations. Ecosystems that recover quickly from minor perturbations are said to be resilient—they can bounce back. More complex communities tend to be more resilient than simpler ones with fewer species because it is less likely that the loss of one or two species will be felt by the community at large—even if some links in the food web are lost, other species are there to fill the void. Of course, if keystone species are lost, the community will feel the effect. The loss of the

ecological succession Progressive replacement of plant (and then animal) species in a community over time due to the changing conditions that the plants themselves create (more soil, shade, etc.).

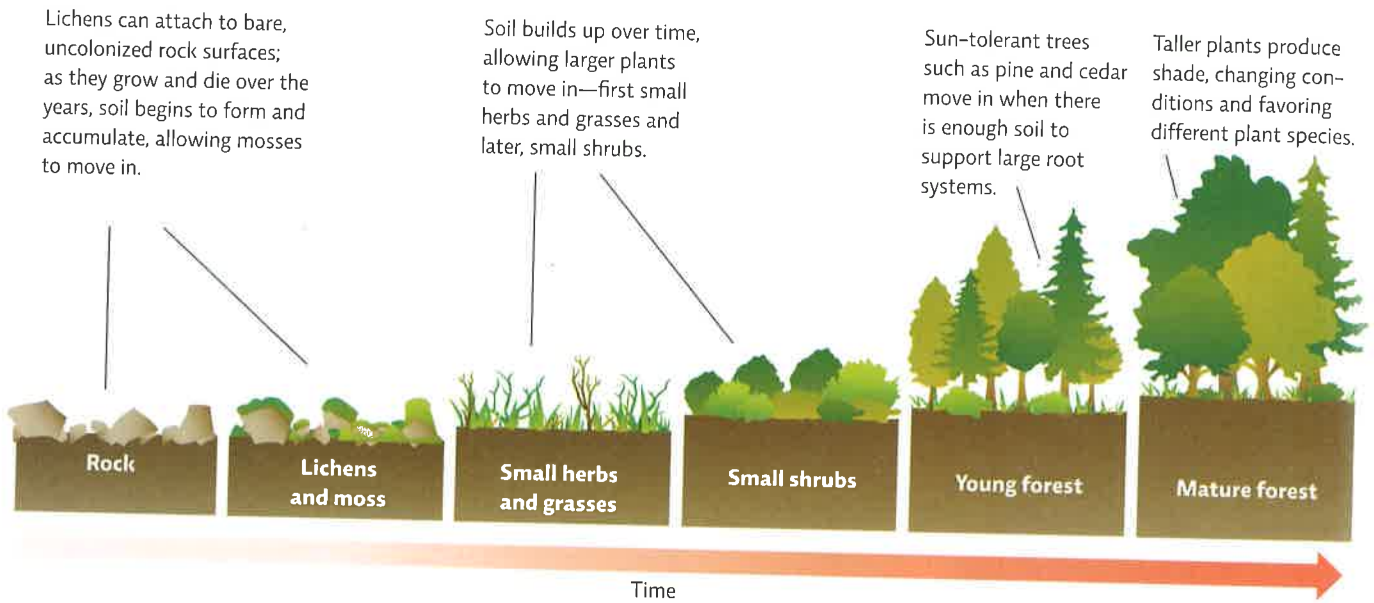
primary succession Ecological succession that occurs in an area where no ecosystem existed before (for example, on bare rock with no soil).

pioneer species Plant species that move into an area during early stages of succession; these are often *r* species and may be annuals, species that live one year, leave behind seeds, and then die.

secondary succession Ecological succession that occurs in an ecosystem that has been disturbed; occurs more quickly than primary succession because soil is present.

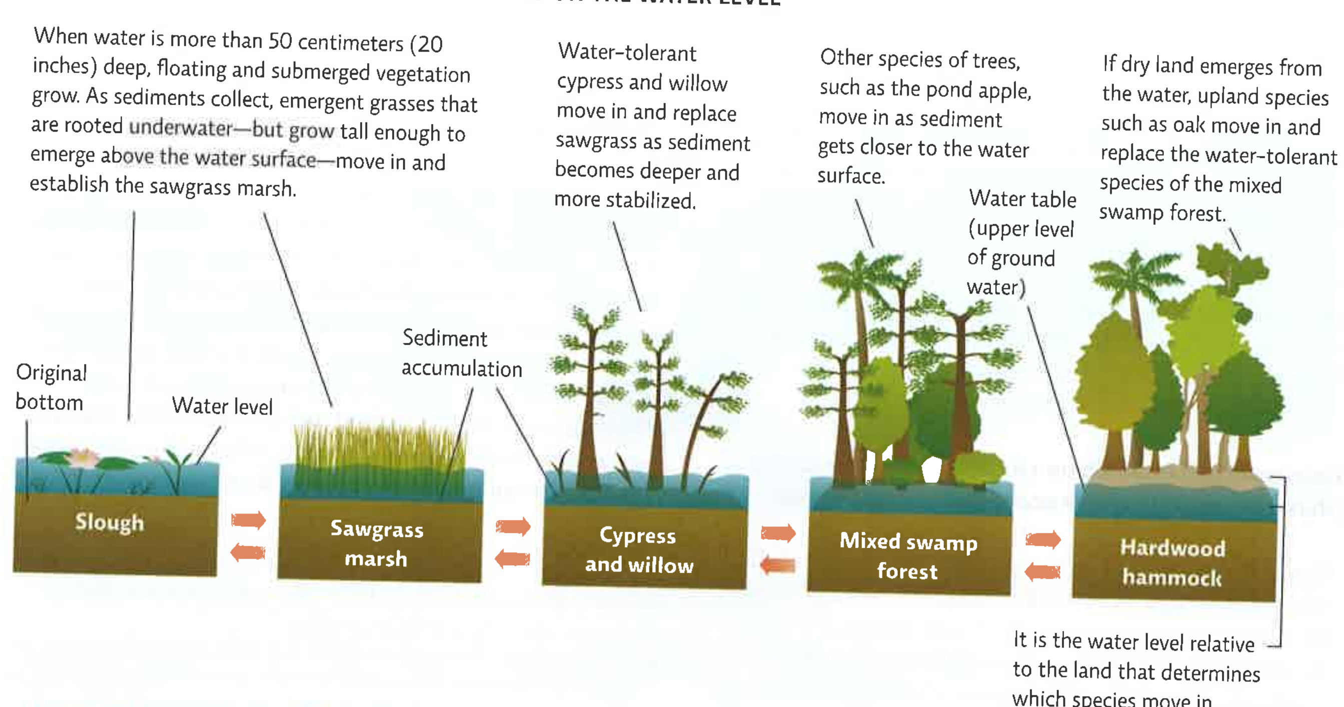
Infographic **9.8** | **ECOLOGICAL SUCCESSION**

FOREST ECOLOGICAL SUCCESSION DEPENDS ON SOIL AND LIGHT AVAILABILITY



↑ In terrestrial ecosystems we see natural stages of succession occur whenever a new area is colonized or an established area is damaged. Sun-tolerant species give way to shade-tolerant ones as more soil is built up, supporting larger plant species.

EVERGLADES ECOLOGICAL SUCCESSION DEPENDS ON THE WATER LEVEL



↑ Ecological succession in the Everglades doesn't necessary follow the tidy predictable sequence seen in terrestrial ecosystems; in fact, periodic fires and the cyclic rainfall patterns may not support a predictable progression at all. Water levels are also important and influence which species move in. Succession in this area can actually go both ways: As ground level changes relative to the water level, an area might flood anew or sediment build-up might continue to raise the land relative to the water level. In the absence of disturbance, succession will progress to the hardwood hammock forest when sediment builds up enough to expose dry land.

alligator from the complex Everglades community would impact many species and change the face of the ecosystem.

Some ecosystems remain in a constant cycle of succession; others eventually reach an end-stage equilibrium where the conditions are well suited for the plants that created them—for example, trees whose seedlings can grow in shady habitat. These species, which can persist if their environment remains unchanged, are called **climax species**. End-stage **climax communities** can stay in place until disturbance restarts the process of succession—although there is debate among scientists over whether any community ever reaches an end point of succession, or continues to change and adapt.

Wetland areas also go through succession, responding to the presence of water and sediment depth. In the Everglades, each ecosystem is guided along this path by its own constellation of forces. Some, like the iconic sawgrass ecosystems, are fire adapted; fire returns them to early stages again and again, where the underwater roots of the emergent plants (those that are rooted underwater but grow above the waterline) such as sawgrass survive and quickly regrow. Others, if left undisturbed, would pass through successional stages of pioneers (grasses) to shrubs or small trees to larger species of trees, depending on the deposition of soil and proximity of the water table to the surface (the top of the groundwater in the area). Others still are guided by the engineering changes of animals such as alligators, whose digging habits provide the foundation for an entire food chain. In each, though, the same general concept applies: As conditions change, other species better adapted to those conditions move in and displace previous residents. [INFOGRAPHIC 9.8]

However precarious their recovery might be, Wood Storks have indeed rebounded in recent years. Some say this rebound is the result of careful conservation efforts—including a restriction on development in certain areas—implemented under the Endangered Species Act. Others insist it is merely the result of above-average rainfall in recent years. For his part, Rogers sees another trend at work. Once again, he says, the storks are trying to tell us something. "They have shifted their center of distribution from South Florida to Central and North Florida," he says. "They're now spilling into Georgia and North Carolina—something we've never seen before." Rogers suspects the shift has something to do with the way climate is changing in the region, though he says much more research is needed before anyone can say for certain. "We're still trying to figure out what that means," he says. "But we know it's a clue to something."◉

climax species Species that move into an area at later stages of ecological succession.

climax community The end stage of ecological succession in which the conditions created by the climax species are suitable for the plants that created them so they can persist as long as their environment remains unchanged.

Research articles referenced in this chapter:
Brix, H., *et al.* 2010. *BMC Plant Biology*, 10: 23.
Rodgers, J.A., *et al.* 1996. *Colonial Waterbirds*, 19: 1–21.

BRING IT HOME

PERSONAL CHOICES THAT HELP

The world is full of weird and wonderful species. Every year we discover new information about how intricate our biological communities are. By restoring habitats and increasing our understanding of the relationships between species, we can better ensure their long-term survival.

Individual Steps

→ Visit a park or nature preserve and watch for signs of species interactions. Do you hear animals or birds; can you see signs of predation or herbivory?

→ Buy a Duck Stamp. Usually purchased by waterfowl hunters for license purposes, nonhunters can purchase a stamp, which supports wetland conservation in the National Wildlife Refuge System.

Group Action

→ The Everglades case study is an example of a very extensive restoration project. Call your local park district or nature preserve to see what restoration work is happening in your area and how you can become involved.

Policy Change

→ Follow the U.S. Fish and Wildlife Service Open Space blog to learn more about wildlife and issues facing conservation (http://www.fws.gov/news/blog).