of the central deserts. Endemic species are very often well-adapted for a particular ecosystem, but unlike species found in a wide variety of environments, their lifecycle may depend heavily on the balance of that ecosystem; they may be ill-equipped to deal with a new disease, predator, or competitor for resources, where a more commonplace species might be more robust, having weathered those challenges many times in its evolutionary past.

The pulse-reserve paradigm of describing rain events in the desert considers deserts as pulse-driven ecosystems. A rain event triggers a pulse of biological activity; some of it is lost to consumption or mortality, and the remainder is committed to a reserve, such as seeds or the water storage of vegetative life like geophytes or succulents. Life in the desert has adapted to dealing with rainfall that arrives in pulses, rather than continuously, and which is sometimes too much and usually too little. For example in the Arctic, the lifecycle of various microflora and microfauna may all but pause during the winter, when the sea is covered in ice and neither new nutrients nor sunlight are available, only to pulse back to life during the summer thaw. In the desert, many species conserve their energy during the dry periods in order to act on the sudden availability of rainwater to replenish their reserves.

The manner of adaptation varies considerably; even in the same desert, a kangaroo is adapted to move long distances from food source to food source in the most energy-efficient way possible, whereas smaller rodents are adapted to move very slowly in order to consume less of their energy with unnecessary movements. Some amphibians in coastal deserts have accelerated larval stages, which allow them to reach maturity faster, improving their chances of survival; on the other end of the spectrum, some burrow-dwelling toads essentially hibernate for the dry season, sealing their burrows off with gelatinous slime that is washed away by the next rainy season. While coastal deserts receive some moisture from fog, this is true only for a portion of the desert, and the pulse-reserve paradigm still holds true for the desert's response to rainfall. Pulses replenish soil water better than fog can, leading to plant growth, and perhaps triggering the mating of certain fauna.

The ecosystems that make the best use of floodwaters include shrubs with grasses at their bases instead of bare soils, because the root matrix of the grasses and shrubs creates macro pores in the soil, encouraging greater infiltration of water. Otherwise, most of the water will simply run right off the dusty, hard-packed surface of the desert, compacted by weathering and wind, glazed by desert varnish, and will eventually evaporate or continue to flow into another environment at a lower elevation.

In the Namib Desert, plants with different types of C_4 photosynthesis, all of which initially fix CO_2 in the mesophyll cells to form oxaloacetate, have different responses to rainfall. Some convert the CO_2 mainly into aspartate, with an inner bundle between metaxylem elements and the Kranz sheath. Others primarily convert the CO_2 into malate, with a single chlorenchymatous or Kranz sheath and centrifugal chloroplasts formed around vascular bundles. The malate converters lack the well-developed grana and higher mitochondrial frequency of the aspartate converters, and increase in abundance as rainfall increases, while the aspartate species decrease as rainfall increases.

Bill Kte'pi

Mid-Latitude Deserts

Mid-latitude deserts are characterized by their dry environments, with distinct topographic and physical features. A suite of different organisms have adapted to living in this harsh environment, and some classic examples range from plants that have adapted to different forms of photosynthesis in order to reduce water loss during the hottest part of the day, to animals that have adapted behavioral patterns to thermoregulate. Humans have also historically inhabited these deserts, and have left behind a rich cultural legacy, even in areas no longer populated. Major threats to this ecosystem include: urbanization, desertification, erosion, and resource overexploitation. Mid-latitude deserts are deceiving at first, because they appear desiccated and devoid of life. On a geologic time-scale, when compared with temperate forest ecosystems, deserts do not jump to the top of the list for primary productivity, but are instead weathered remnants that are severely resource constrained. However, mid-latitude deserts are rich centers of life, often with organisms that have adapted to become especially suited to these harsh environments. Mid-latitude deserts are also home to a diverse range of human inhabitants, who have similarly adapted to the desert environment. While deserts can seem unforgiving, it is worthwhile to traverse the dry landscape. Some great examples of the diversity of desert dwellers can be best exhibited through environmental adaptations and defense mechanisms, ranging from the spines commonly found on cacti to the unique defense strategies employed by horned lizards. Deserts are visually stunning and extreme environments, well worth the effort of exploring first-hand.

Desert Formation

Mid-latitude deserts are globally distributed. They occur approximately 25–35 degrees north or south of the equator (often referred to as the horse latitudes). They are perhaps the most common type of deserts and account for some of the most famous deserts in the world, like the Sahara in Africa, the Great Sandy Desert in Australia, and the Sonoran Desert in North America. Mid-latitude deserts are formed when dry air circulates down to the ground after having emptied its moisture in the tropical latitudes of the world. As the sun hits the Earth, the tropical latitudes receive the most solar radiation; this causes warm wet air to rise to the atmosphere.

As the air rises, the wet tropics receive nearly all of the precipitation in it, leaving dry cool air to circulate down from the atmosphere at about 30 degrees north or south of the equator. This dry air accounts for the high aridity and precipitation patterns observed in most mid-latitude deserts. Most deserts can be characterized by the ratio of precipitation to evaporation. In most mid-latitude deserts, evaporation will frequently be greater than the total precipitation that hits the ground. Since "mid-latitude desert" is a very broad classification, and they are widely distributed across the world, there is quite a bit of variation in total precipitation that these deserts receive. Most of these deserts are extremely arid, and tend to have less than 9.84 inches (25 centimeters) of annual precipitation. The low precipitation also results in low cloud cover in most of these deserts. Low cloud cover leads to high daily temperature variation. In some of the most extreme cases, temperatures can reach 104 degrees F (40 degrees C) during the day and close to 32 degrees F (0 degrees C) at night. The cool, dry air that flows into mid-latitude deserts often can become very violent and triggers massive sandstorms, with walls of dust reaching .93 miles (1.5 kilometers) into the air, and with winds reaching 37–62 miles (60–100 kilometers) per hour.

Mid-latitude deserts have distinctive geophysical features that are indicative of this type of habitat. Often, mid-latitude deserts have vast stretches of sand dunes; some of the largest dunes in the world occur in the western Sahara Desert, and some of the tallest reach nearly 0.62 miles (1,000 meters) in height. Much of mid-latitude deserts are covered in dry, rocky outcrops, or even vast salt flats. The largest of these salt flats is Salar de Uyuni in the northern extent of the Atacama Desert, and is approximately 4,054 square miles (10,500 square kilometers) in area. Rivers are rare in mid-latitude deserts, but some, like the Nile, flow through vast portions of the Sahara. Usually, rivers that run through mid-latitude deserts tend to originate in high-elevation regions that receive more precipitation. Oases are often another source of freshwater in mid-latitude deserts, and are typically formed by aquifers or underground river systems. Both rivers and oases are areas where most of the diversity of organisms in mid-latitude deserts can be found.

Life in Mid-Latitude Deserts

Most mid-latitude deserts are less than 20,000 years old, making them relatively new ecosystems. Mid-latitude deserts grew in size after the glaciers that covered the northernmost and southernmost latitudes of the world during the last glacial maximum began to retreat, and historically temperate regions underwent desertification. However, even while mid-latitude deserts are relatively young in geologic and evolutionary timescales, they are still home to many endemic taxa with very interesting evolutionary histories.

Mid-latitude desert organisms have evolved traits that allow them to survive the harsh conditions of limited water availability, high temperatures, scarce food resources, high competition, and high predation. The evolution of life in the desert makes mid-latitude deserts interesting places for evolutionary biologists to consider evolutionary phenomenon like convergent evolution. Convergence is when similar traits evolve in organisms that do not share a common ancestor, mostly because of shared selection pressures in different regions of the world. Examples of organisms that have evolved convergent traits in mid-latitude deserts are the Kangaroo rats (*Dipodomys)* of North American mid-latitude deserts, and the Australian mid-latitude desert Hopping mice (*Notomys*). To prevent herbivory, succulent mid-latitude desert plants have also evolved convergent traits, like the thick spines in North American cacti and African *Euphorbia* species.

Life in the mid-latitude deserts is heavily dependent on water availability and the organisms' physiological and behavioral adaptations to deal with high temperature fluctuations. Water in mid-latitude deserts is restricted to a few main sources like aquifers, oases, and rivers. It is along these riparian areas where most of the biodiversity in mid-latitude deserts can be found. However, unique organisms have adapted to extreme aridity by drawing water from fog or water condensation from morning dew, as is the case with *Euphorbia* in the Atacama Desert (the driest mid-latitude desert in the world) in western South America. Behavioral adaptations also allow organisms, especially vertebrates, to cope with the high temperature fluctuations in mid-latitude deserts. Many desert organisms are primarily nocturnal, and simply avoid activity during the warmest periods of the day. Adaptation and evolution have resulted in deserts rich in endemic biodiversity. The Sonoran Desert is North America's most biodiverse mid-latitude desert.

Biodiversity in mid-latitude deserts is threatened by habitat disturbance, depletion of water resources, and urbanization. As people continue to colonize the mid-latitude deserts of the world, water resources are depleted, activities like overgrazing change the structure of the vegetation and animal communities of the desert, and cities expand into areas where human life may not be sustainable. All three of the anthropogenic disturbances devastate the endemic and rare biodiversity of desert organisms, and further research is required to fully understand how these disturbances impact the native species of the mid-latitude deserts of the world.

The Zebra-Tailed Lizard in Arizona's biodiverse Sonoran Desert is a heat-tolerant lizard that can remain active in midday when high temperatures force other types of lizards to seek shelter. (Thinkstock.

Natural Resources of Mid-Latitude Deserts

Mid-latitude deserts are homes to the largest terrestrial oil deposits in the world. The oil reserves in the Middle East and in northern African mid-latitude deserts are among the largest in the world. A total of 6 of the 10 largest oil-producing nations are in the deserts of these regions, including: Iraq, Kuwait, the U.A.E., Iran, Saudi Arabia, and Lybia. In a world so heavily dependent on oil and other fossil fuels for transportation and energy production, mid-latitude deserts are important global regions for production of these fossil fuels. Drilling for oil and improper management of oil production has impacted the deserts in Iraq and Kuwait, especially from recent wars and political conflicts. During the Gulf War in the early 1990s, oil fields in Kuwait were burned and millions of barrels of oil were released into the sands of the desert, devastating wildlife and vegetation communities. Restoration efforts are still ongoing. Oil production and regulation in the mid-latitude deserts of the world should be carefully monitored and regulated to protect endemic and threatened organisms that occupy these parts of the world.

> **"Biodiversity in mid-latitude deserts is threatened by habitat disturbance, depletion of water resources, and urbanization."**

Mineral resources are abundant in mid-latitude deserts. Because of high rates of evaporation, minerals leached from rainwater and groundwater are frequently accumulated in the most arid regions of mid-latitude deserts. Salts are frequently accumulated near the surface in many mid-latitude deserts. One of the most salt-producing mid-latitude deserts is the Atacama Desert in South America. Other evaporites (minerals sediments that accumulate after evaporation brings the elements out of solution) commonly found in mid-latitude deserts are Gypsum and Boron. Gypsum also accumulates belowground, and is responsible for the giant crystals in the vast cave systems in the deserts of the southwestern United States (e.g., Lechuguilla Cave). Important metals are also often accumulated in the soils of mid-latitude deserts. In North America, copper production in the Sonoran and Chihuahuan Desert is a major industry. Other metals of importance that can be found in mid-latitude desert are zinc, iron, and lead. Economically valuable metals like gold, silver, and uranium are also frequently mined from many of the mid-latitude desert regions of the world.

Management, extraction, and processing of these mineral resources frequently take a toll on the delicate desert ecosystems. In the United States, open-pit copper mining, especially in deserts of Arizona and New Mexico, modifies vast areas of the landscape, which will likely never recover from such a major disturbance. The processing of these resources in refineries also takes a toll on desert ecosystems, and often results in heavy-metal contamination of the soils and bioaccumulation of metals like lead, copper, and zinc in the plants and animals of the desert. Often, the heavy metal contamination and bioaccumulation can be detected up to 40 miles from a refinery.

Mid-latitude deserts provide natural resources that can be harvested with minimal ecological impact and multiple global benefits. Historically, the major rivers that dissect many mid-latitude deserts have been regulated to produce hydroelectric power. Even though damming rivers to produce hydroelectric power is damaging to the desert ecosystems, the sustainability and overall ecological consequences of energy production from these sources may be better and more sustainable than the burning of fossil fuels. Globally, about 2 percent of energy production comes from hydroelectricity, and only about .1 percent comes from dams in mid-latitude deserts.

However, mid-latitude deserts are ideal for the development of solar and wind energy production. These sources of energy have the potential to meet approximately 33 percent of the global energy demand, and mid-latitude deserts have the potential to become major producers of sustainable energy production across the globe. Major solar energy production ventures are already under way in the Mohave Desert in the United States (e.g., by Solar Energy Generating Systems). The mid-latitude deserts have the highest solar energy production potential in the world. Places like the Sahara, the Arabian Peninsula, and the Australian deserts all are great regions for collecting solar energy. The geomorphology of the mid-latitude deserts makes these areas suitable for development of wind-energy production. Desert areas in Texas, California, and New Mexico in the United States are already being developed for major wind-energy production. Currently, 2.5 percent of U.S. energy comes from wind production; with increased development, up to 20 percent of the energy production in the United States can come from sustainable wind energy production by 2030.

People in Mid-Latitude Deserts

Mid-latitude deserts have a rich history of civilizations that have developed in these arid global regions. Among the most notable are the civilizations of ancient Mesopotamia that developed along the major fertile river valleys in the mid-latitude desert regions of the Middle East. The heart of ancient Mesopotamia revolved around the riparian habitat provided by the Tigris, Euphrates, and Nile, but the people of these civilizations developed their cultures and societies in the harsh conditions of the mid-latitude deserts.

In North America, the mid-latitude deserts of the southwestern United States and northern Mexico are homes to ancient Native-American tribes, like the Anasazi (which are ancestors to the more recent Pueblo people), the Mogollon, and the Hohokam. Until the early 1900s, native Aboriginal cultures (Wangkangurru people) thrived in the Simpson Desert (an Australian mid-latitude desert) by moving between reliable well and ground water resources. In the Sahara, the Berber people, and most notoriously the Tuareg people, have also historically lived nomadic herding and trading lifestyles in this vast desert region.Currently, mid-latitude deserts are occupied by a wide variety of people. In the United States, Native-American tribes have been drastically restricted to reservations and now account for less than five percent of the total population in the desert southwest.

However, some mid-latitude deserts have retained many of the people's ancestral traditions. For example, in the Gobi Desert, most people live a nomadic herder lifestyle. The decedents of the Atacama and Aymara native people of the Atacama Desert still herd llamas and alpacas through this mid-latitude desert.Urbanization has dramatically changed the populations of the mid-latitude desert. Some of these regions of the world are experiencing rapid population growth as cities grow and infrastructure connects previously isolated regions. This urbanization movement is particularly pronounced in areas where mineral and other natural resource exports stimulate the regional economy. One example is the growth of major population centers in the major desert oil-producing nations. Major economic growth has stimulated the population and economic growth in major desert cities like Dubai in the United Arab Emirates. In the United States, mid-latitude deserts' major economic and urbanized areas include cities like Phoenix and Tucson, Arizona. Additionally, there are major border cities that are important for North American trade, including the cities of El Paso, Texas, and Ciudad Juarez, Chihuahua, Mexico. These cities all have populations ranging from 450,000 to 1,500,00 people. This growth has major impacts on the terrestrial ecosystems of mid-latitude deserts.

Threats

There are four major categories of threats to mid-latitude desert ecosystems, including: urbanization, desertification, erosion, and resource exploitation. Additionally, there are miscellaneous threats, usually tied to anthropogenic pollution. These include nuclear waste and solid waste disposal, increased irrigation pressures, increased grazing, and irresponsible recreational vehicle use. While all of these threats are imminent and pose great danger to the maintenance of healthy deserts, if steps are taken now, scientists can mitigate damage to these unique ecosystems and preserve desert ecosystems for future generations to enjoy.

Urbanization is one of the key threats to desert ecosystems. Development and construction practices can be highly detrimental to fragile biotic crusts that cover desert soils. Along with development and construction come the associated needs for water and land resources, both of which stress already limited resources (water is very limited in desert ecosystems, and land well-suited for development may also be limited). Urbanization pressures are also inherently tied sprawl, which increases the footprint of urban centers on surrounding landscapes—a good example of this is the sprawl associated with cities such as Las Vegas, which required enormous resource infrastructure to survive in environments that are not naturally suited to support large populations. Anthropogenic pollution is also likely to increase with urbanization, and additional public works networks (to supply people with water, or provide waste processing) will also need to be established as new areas become urbanized.

With global warming there are increasing rates of desertification, which is often associated with increased likelihood of drought, loss of biodiversity, and decreased soil moisture (depending on specific geographic positioning). Desertification is the process of land changing from productive or arable land to less productive deserts because of climate change and human-induced land changes such as deforestation or clearing for agriculture. This is a counterintuitive threat, since desertification effectively creates deserts; however, desertification usually leads to nutrient-depleted deserts that do not support native healthy desert animal and plant communities, and are usually located in regions where deserts would not naturally occur.

Correlated with urbanization and desertification comes land degradation and increased erosion pressures across desert landscapes. Biotic crusts, which cover many desert landscapes, can support a great diversity of microorganisms, but are very sensitive to environmental changes. With landscape disturbances, soil crusts may fragment, decrease functionality within desert ecosystems, and lead to a negative feedback loop, leading to less-productive desert ecosystems. Deserts, while not necessarily noted for their abundance of vegetation, are highly susceptible to erosion because of low vegetation cover, and with increased disturbances they can erode even faster. This means that the desert does not only become drier in light of climate change, but as a result could have significant changes in vegetation, decreased soil moisture, and increased erosion. Over time, land degradation and erosion can completely destroy productive desert ecosystems.

Resource exploitation can rapidly diminish healthy ecosystems. Deserts are no exception, even if on the surface they look dry and covered with spiky cacti, they offer a wealth of below-ground resources. Human energy needs are only increasing as the world's population surpasses 7 billion people. Oil extraction and associated extraction technologies are not only greatly disruptive to these ecosystems, but also pose hazardous environmental threats in the form of oil spills and other chemical contamination. Deserts can also be filled with other valuable resources that are useful for energy, such as petroleum oil, coal, and natural gas extraction; and precious metals such as gold and diamonds.

Israel Del Toro

Paleodeserts

Data on ancient sand seas (vast regions of sand dunes), changing lake basins, archaeology, and vegetation analyses indicate that climatic conditions have changed considerably over vast areas of the Earth in the recent geologic past. During the last 12,500 years, for example, parts of the deserts were more arid than they are today. About 10 percent of the land between 30 degrees N and 30 degrees S is now covered by sand seas. Nearly 18,000 years ago, sand seas in two vast belts occupied almost 50 percent of this land area. As is the case today, tropical rainforests and savannas were between the two belts.

Fossil desert sediments that are as much as 500 million years old have been found in many parts of the world. Sand dune–like patterns have been recognized in presently non-arid environments. Many such relict dunes now receive from 3.15 to 5.9 inches (80 to 150 millimeters) of rain each year. Some ancient dunes are in areas now occupied by